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LANDING SYSTEM RELIABILITY AND SAFETY MODEL.(U)

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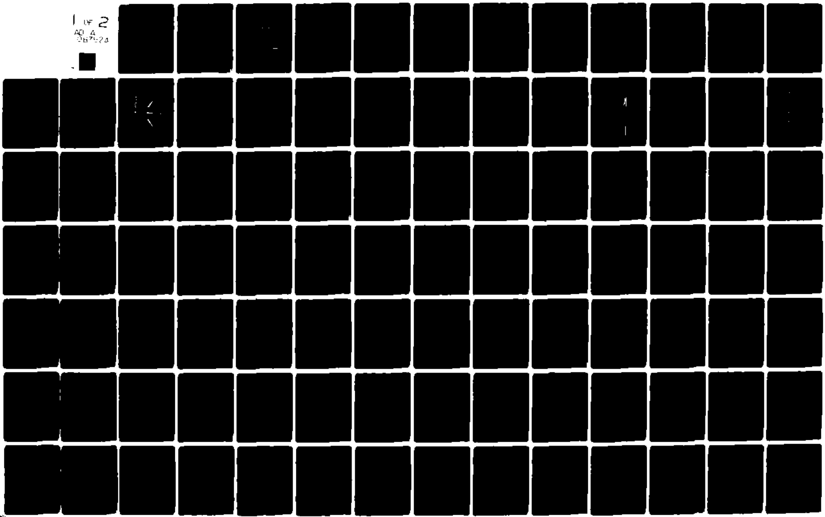

AFFDL-TR-79-3107 LEVEL II

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LANDING SYSTEM RELIABILITY AND SAFETY MODEL

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UNIVERSITY OF DAYTON
MANAGEMENT SCIENCE
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AUGUST 1979

TECHNICAL REPORT AFFDL-TR-79-3107
Final Report for Period September 1974 — June 1979

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AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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A total systems analysis procedure for identifying the safety hazards and risks associated with the use of a defined flight control system for low visibility approach and landing (Category III) was developed. The analysis includes the ground transmitting system, airborne automatic flight control system, pilot and copilot operating in the system, and crew procedures. Actual data from Category III experience in a specially equipped C-141 aircraft, along with equipment failure data from C-141 fleet experience was used to test and confirm the modeling techniques.

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FOREWARD

This document is the technical report on a total systems analysis procedure developed for identifying the safety hazards and risks associated with the use of a defined flight control system for low visibility approach and landing (Category III). The analysis includes the ground transmitting system with monitoring, airborne automatic flight control, the pilot and copilot operating in the system, and crew procedures. Actual data from Category III experience in a specially equipped C-141 aircraft, along with equipment failure data from C-141 fleet experience, was used to test and confirm the modeling techniques.

The reliability/safety analysis program reported herein is a part of a broad joint Federal Aviation Administration (FAA) and Air Force (AF) effort for gathering data on the psychological, physiological, and procedural aspects of landing a large turbojet aircraft in actual low visibility weather down to and including Category IIIc weather (zero ceiling and zero visibility).

There are a number of reports and papers dealing with parts of the total program. For the reader who needs an insight into the total program, extracts of important details are included in the appendices. Where more detailed information and data are required, references may be obtained for further study.

Program management for the overall joint program has been provided by the Air Force Flight Dynamics Lab (AFFDL/FGT) under Project 2187, Low Visibility Terminal Area Operations, with Reliability/Safety Analysis support of the All Weather Landing System Program (AWLS) provided by the University of Dayton under contract F33615-74-C-3075, dated June 3, 1974. Flight tests were conducted by the 4950th Test Wing of the Aeronautical Systems Division at Wright Patterson Air Force Base, Ohio.

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SECTION I
INTRODUCTION

1.1 OBJECTIVE

The objective of the work reported in this document was to provide an analytical means whereby an existing or proposed airborne/ground guidance system could be analyzed from a safety/reliability and risk assessment point of view. A further objective was to test the analytical system (model) with actual flight experience data and correct it, where needed, in order to increase confidence in the model.

1.2 BACKGROUND

The aviation community and the FAA have been working for many years toward the ultimate goal of all-weather landings. The high cost of disruptions to jet flights caused by weather diversions has given impetus to development of an all-weather capability for jet aircraft. The requirements of the military for all-weather operations are self evident and of high priority.

Standards of performance have been developed by special committees working under the AWOP (All Weather Operations Panel) of the ICAO (International Civil Aviation Organization). With the establishment of ICAO performance standards and definition of approach limitations based upon decision height and runway visual range (RVR), (see Table I), very significant developments have taken place in the fields of guidance and control. A result of these developments is the acceptance of fully automatic landings which require total reliance on the autopilot, at least as the prime system.

Although instrument flight has progressed to a remarkable level of capability over the years, the attainment of safe and routine low visibility landings is yet to be realized. With some minor exceptions, the currently accepted operational limitation in the aviation community is 1200 feet runway visibility. Although several organizations have conducted flight test programs to investigate this unknown environment and made significant contributions, the problem of complete all-weather capability has not been solved.

In an effort to gain more experience and data and to perhaps better define this environment, the FAA and the Air Force jointly conducted an All Weather Landing System (AWLS) test program in which this reliability/ safety analysis program played an important role.

Table 1

International Civil Aviation Organization Weather Criteria

Category	Decision Height (feet)	Runway Visual Range (feet/meters)*
I	200	2600/800
II	100	1200/400
IIIa	none	700/200
IIIb	none	150/50
IIIc	none	0/0

* note: While one meter is 3.280 feet, the above definitions indicate the approximately equivalent measurements in feet/meters which are the generally accepted values.

1.3 HISTORICAL DEVELOPMENT OF PRESENT PROGRAM

FAA interest in the development of an all-weather landing capability in the C-141 began early in the basic C-141 development program. Initially, Category II capability was of primary interest. Later, interest was shown by the FAA in the development of a Category III capability in the C-141. The Lockheed-Georgia Co. made a series of modifications to the Category II system in NC-141A-61-2775 and, starting in 1968, carried out a series of flight tests of the resulting Category III configuration for the FAA at the National Aviation Facility Experimental Center (NAFEC), Atlantic City, New Jersey. The objective of the flight tests was to obtain adequate data to define minimum performance and equipment/requirements criteria for Category III operations and to identify existing system deficiencies which were prohibiting actual Category III operations. The test is reported in a NAFEC report, NA-69-18 (RD=69=34), dated October 1969. At the termination of the test conducted by Lockheed, NC-141-61-2775 was delivered to the Aeronautical Systems Division (ASD) at Wright Patterson Air Force Base, Ohio for continuation of testing. The ultimate goal was to validate the C-141 AWLS for Category III operation.

Development of the C-141 AWLS was established as a joint FAA/USAF effort. The guidelines for working relations between the two organizations were defined in Interagency Working Agreement, DOT-FA-70-WAI-173, dated October 1969.

The ASD (4950th/EN) flight test program, under the supervision and engineering direction of the Systems Engineering Directorate of ASD, lasted from 13 Dec 1969 until 11 April 1972. The results of the program are reported in Flight Test Report ENE-72-20, dated 14 Nov 1972. The flight test objectives were never attained since, as reported, "the level of performance of the C-141 AWLS was so poor that the primary effort during this period of testing was forced to be directed, almost exclusively, toward trouble shooting and correcting AWLS problems." No conclusions pertaining to the flight test objectives could be made.

At this time, the responsibility for test direction and management was transferred to the Traffic Control and Landing (TRACALS) System Project Office (SPO)

at the Electronics Systems Division (ESD) at Hanscomb Air Force Base in Cambridge Mass. At the request of ESD, the responsibility for continuing the work to fulfill the agreement with the FAA, was transferred to the Flight Dynamics Laboratory at Wright Patterson Air Force Base. ESD retained overall mangement responsibility.

After inspection of the system and consultation with the 4950th Test Wing of ASD and the FAA, AFFDL recommended that a complete clean-up and updating of the AWLS and aircraft be accomplished. It was specific that the clean-up include at least the installation of a dual inertial system (INS), installation of a modern flight control system, and the elimination of all inputs to the AWLS from the C-12 compass system which had been a primary source of trouble.

A contract was let to the Lear-Siegler, Inc. Contract Maintenance facility at Mobile Alabama for the clean-up of the AWLS and the accomplishment of an aircraft periodic inspection. The aircraft was at Mobile for almost nine months. The first flight following clean-up was on 26 Oct 1972. After safety-of-flight discrepancies were corrected, the aircraft was returned to Wright Patterson Air Force Base in Nov. 1972.

With the return of the aircraft to WPAFB, several efforts were begun simultaneously. The primary effort was to optimize the AWLS and the instrumentation, and to start a failure/degraded performance computer simulation. Also, the integration of the Maxson Independent Landing Monitor radar, later referred to as the ALR, and the Sperry Electronic Attitude Director Indicator (ALR/EADI) was initiated. The results of this effort and the optimization and pre-experimental flight test phases are reported in Technical Memorandum AFFDL-TM-109-FGSA, dated April 1974 and cover the period 1 Nov. 1972 to 19 Feb. 1974. It should be noted, however, that the ALR/EADI (later called ILM/EADI) equipments were not used during the operational flight tests nor in the safety/reliability analysis.

In 1974, interest developed in computer modeling techniques as a tool for safety and reliability analysis of the total ground/airborne all weather landing system. Various mathematical modeling schemes exist which deal with parts of

the total ground/airborne system in assessing safety and reliability. None have dealt with the total ground/airborne system in a Category III situation using actual data from Category III experience to test and confirm the modeling techniques.

A contract was established with the University of Dayton in 1974. The program is unique in that the modeling techniques developed have been tested and adjusted using data from actual Category III landing experience in a specially equipped C-141 aircraft. As a result, a total ground/airborne system computer-modeling technique has been developed, tested and validated to a degree that it can be used with a high degree of confidence as a design tool in future system developements and risk assessment.

SECTION II

SYSTEM DEFINITION AND CONFIGURATION

The emphasis in this reliability/safety analysis stressed a total systems concept which included modeling of the ground-based Instrument Landing System (ILS) with monitoring, the airborne control system used in the automatic mode with the pilot and crew "in the loop", and both safety pilot and crew procedures. (Figure 1). A few words about each is in order.

Due to the limited number of certified Category III ILS ground installations, the flight test program was planned from the initial phases to gain Category III weather experience using Category II ILS ground installations. A typical Category II ILS provides an oncoming aircraft with guidance information on height and ground track for a visual take-over by the pilot at 100 feet. Therefore, it was necessary for the airborne control system of the test aircraft to be modified in order to provide additional automatic guidance capabilities below the 100 foot altitude that are required for a Category III landing. These additional guidance capabilities would allow for automatic flare, decrab, and rollout.

The basic control system for the C-141 test aircraft included the flight control system and the Category II all-weather-landing-system (AWLS). These systems were modified and augmented to provide the additional automatic capabilities necessary for a Category III landing using the previously mentioned Category II ILS. The modifications included such items as the Sperry 350 B Attitude Director Indicators (ADIs), Dual C-5 (Wilcox 800C and 806C) ILS receivers for glideslope, dual Collins (51RV2B) ILS receivers for localizer, dual flare computers, an updated Test Program Logic Computer (TPLC), and dual radar altimeters. The system was augmented with a Category III adaptor (designed and built by AFFDL) for aircraft functions required below 100 feet and dual Litton (LTN-51) inertial platforms. Also provided was a digital data recording system, a test director s console with basic flight instruments to allow additional pilots and engineers to monitor progress along the flight profile. In addition, a Numax Independent Landing Monitor and a Sperry Electronic Attitude

TOTAL SYSTEMS APPROACH

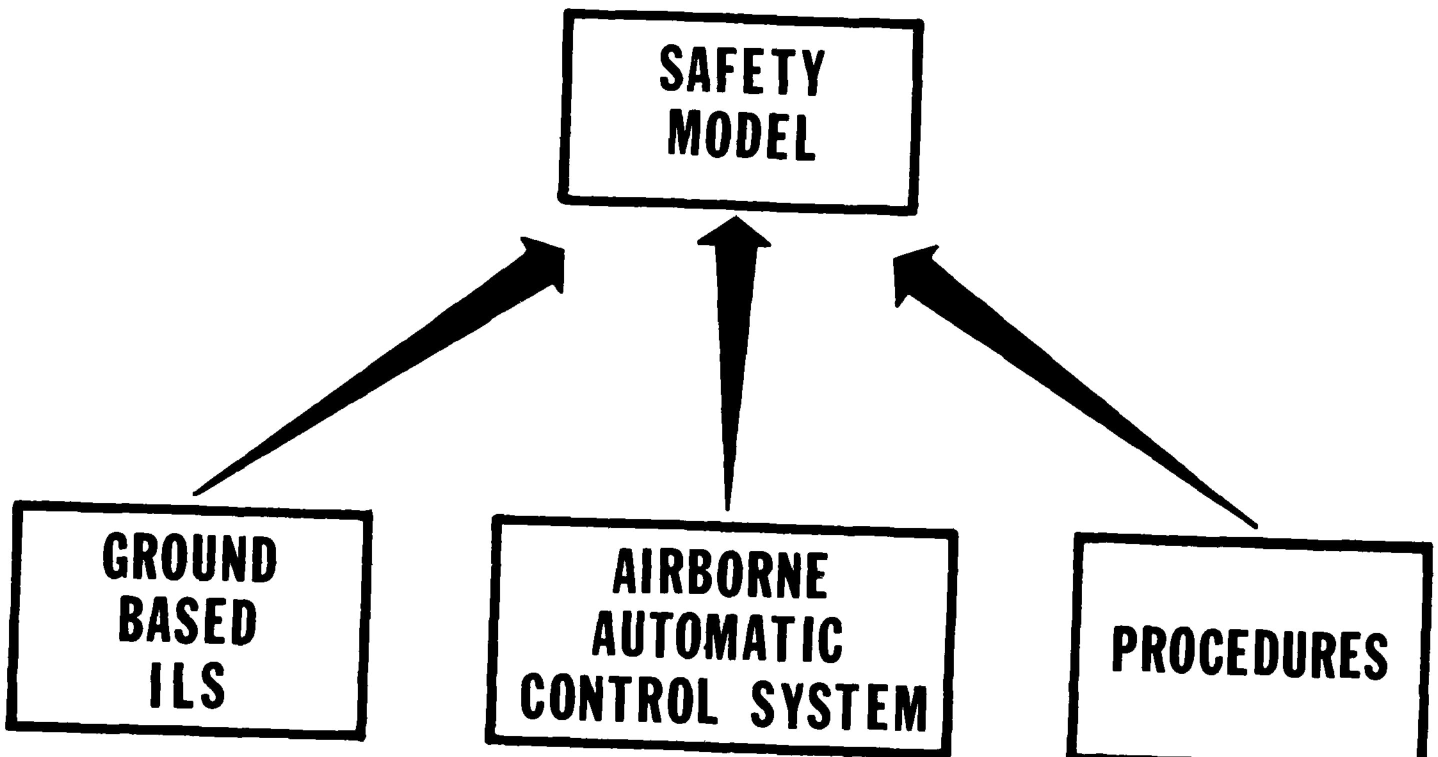


FIGURE 1

Director (EADI) were installed for experimental purposes and with the hope that they could eventually be used in the program. The Independent Landing Monitor (ILM) provided a perspective view of the runway on approach and during landing which was superimposed on the Sperry EADI in such a way that the runway could be seen as background to the steering information provided by the EADI. However, because of many maintenance problems with the ILM, the system was not used effectively during the test program and was not a part of the safety/reliability analysis.

A functional block diagram of the system initially used is illustrated in Figure 2. During the latter stages of the flight test program, an alternate system configuration was evaluated. This configuration employed a Simplified Terminal Area Control Computer (STACC) which was developed as the first step towards replacing the C-141 guidance and control system with more advanced (digital) avionics. The STACC was more efficiently designed than its counterpart equipment by virtue of combining functions and by using current electronics. The STACC replaced the following standard C-141 avionics: (1) flight director computers, (2) automatic flight control system (ATCS) coupler, (3) flare computers. In addition to this equipment, the STACC included circuitry to replace the Category III adapter that converted the standard C-141 Category II system into a Category III AWLS. The STACC consisted of two (2) identical and interchangeable boxes that were cross monitored and equalized before feeding into the downstream autopilot computers. The equalized output of one box was used to drive the autopilot and the copilot display systems and the equalized output of the second box was used to drive the pilot and test director's display systems. The STACC system embodiments are shown in Figures 3, 4, and 5.

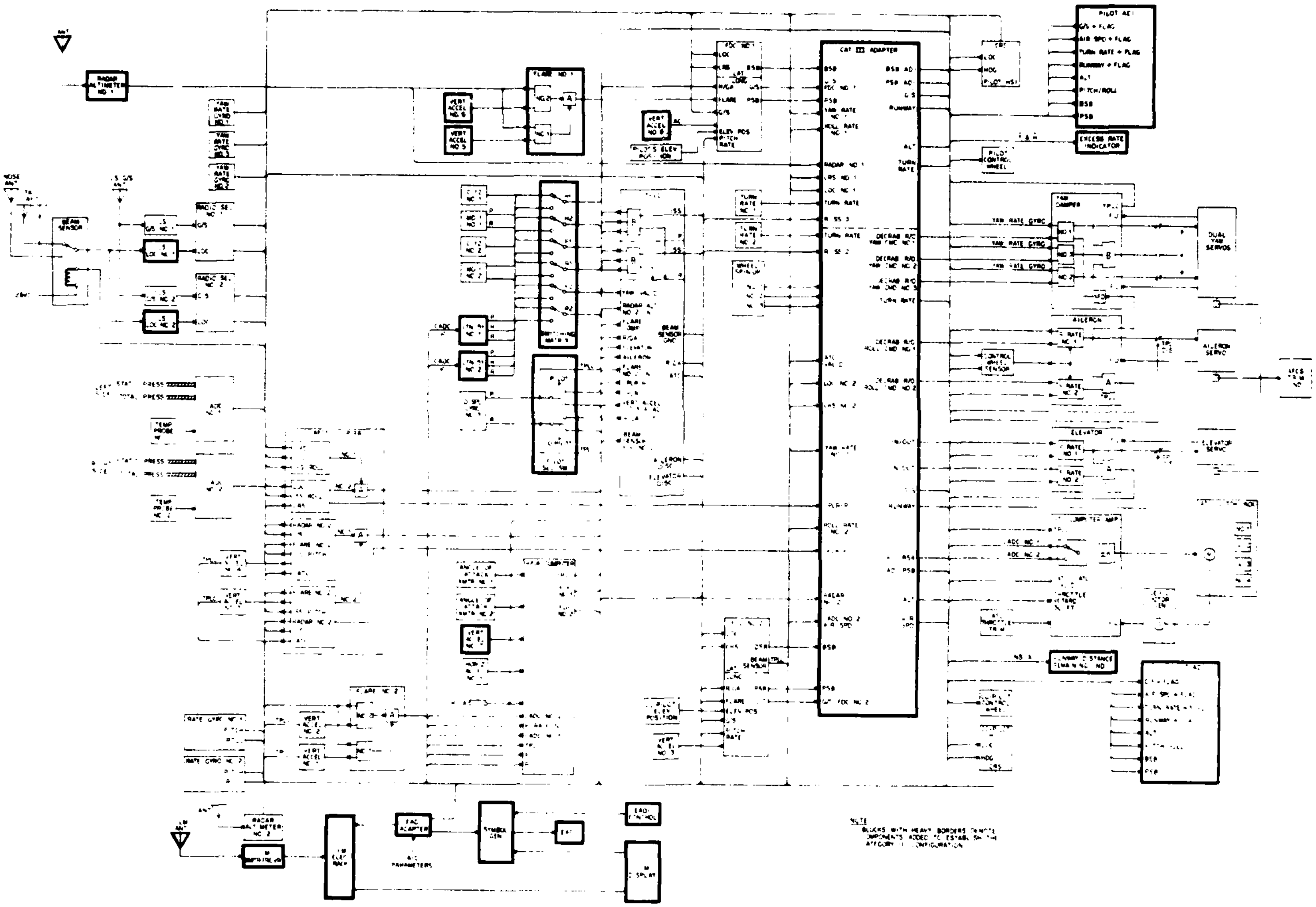


FIGURE 2 AWLS System Block Diagram

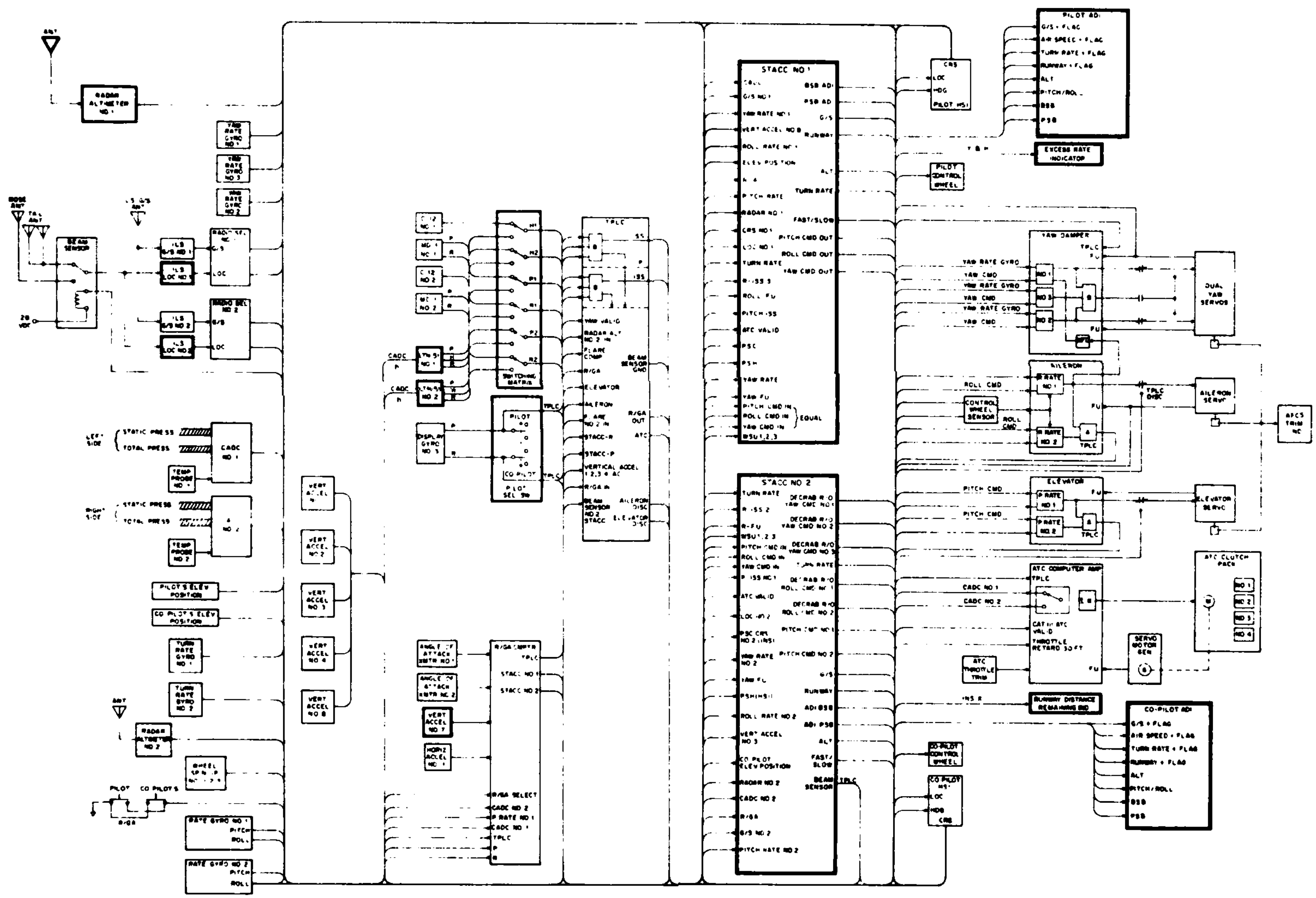


FIGURE 3 STACC System Diagram

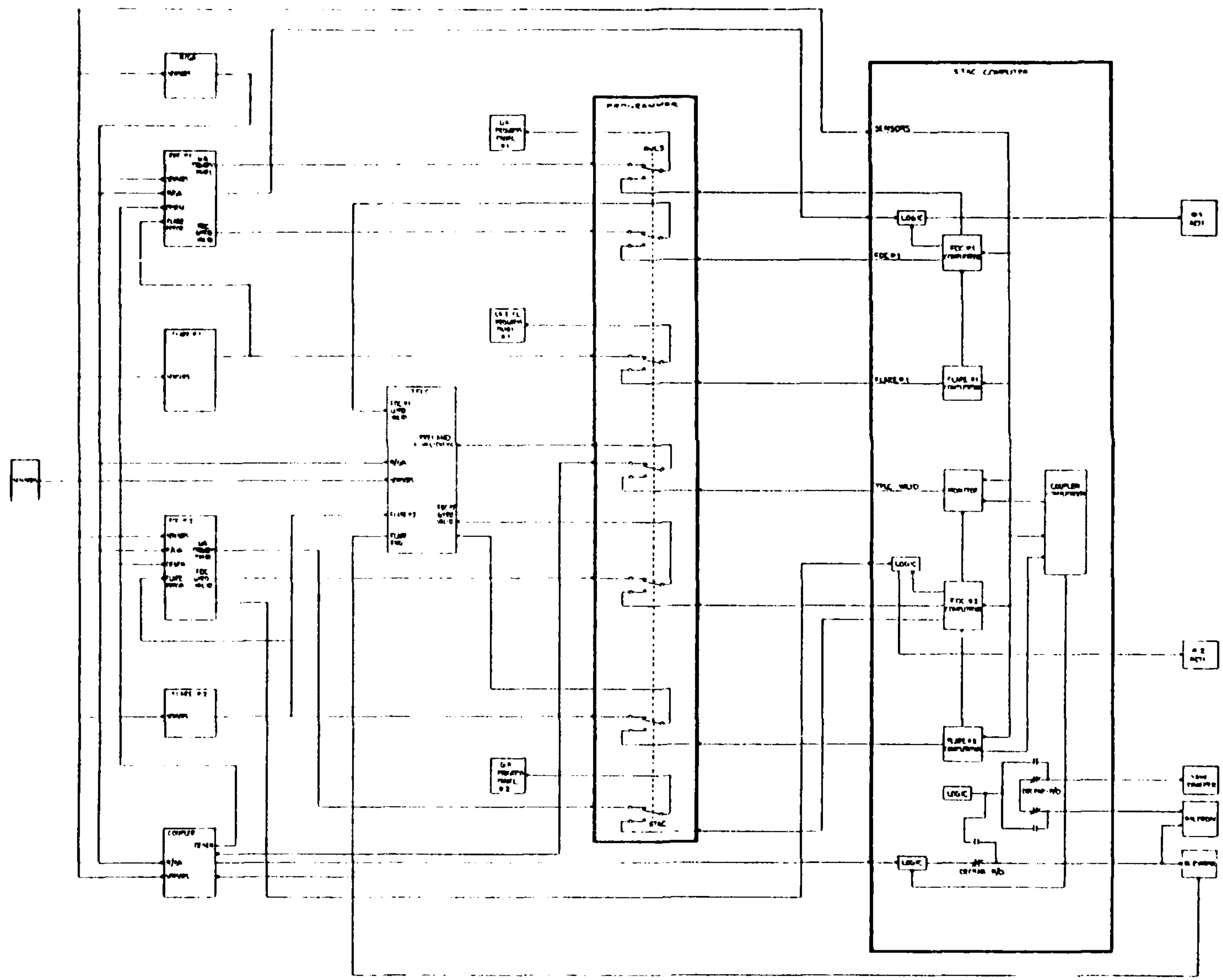


FIGURE 4 STACC Logic Diagram

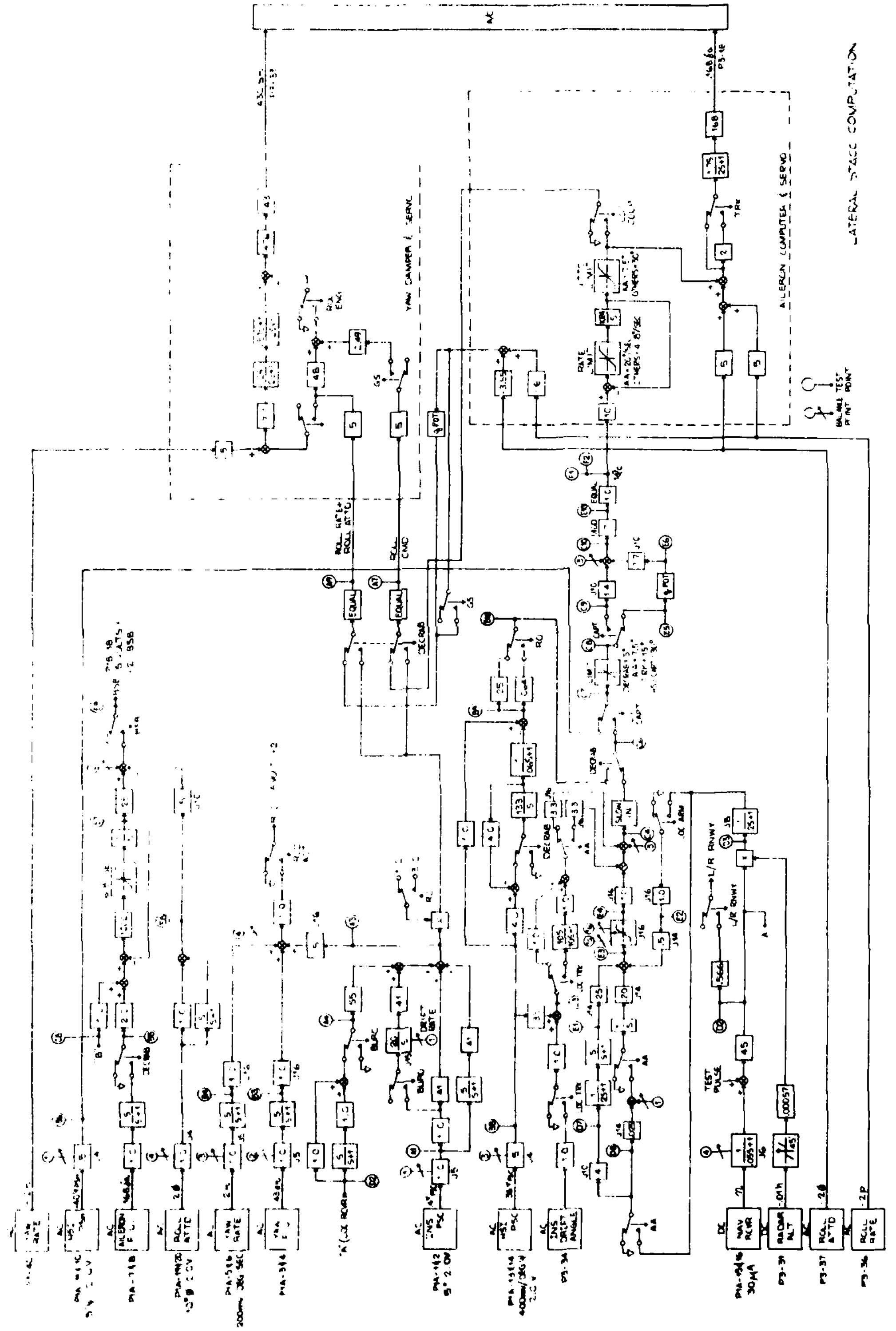


FIGURE 5 Lateral STACC Computation

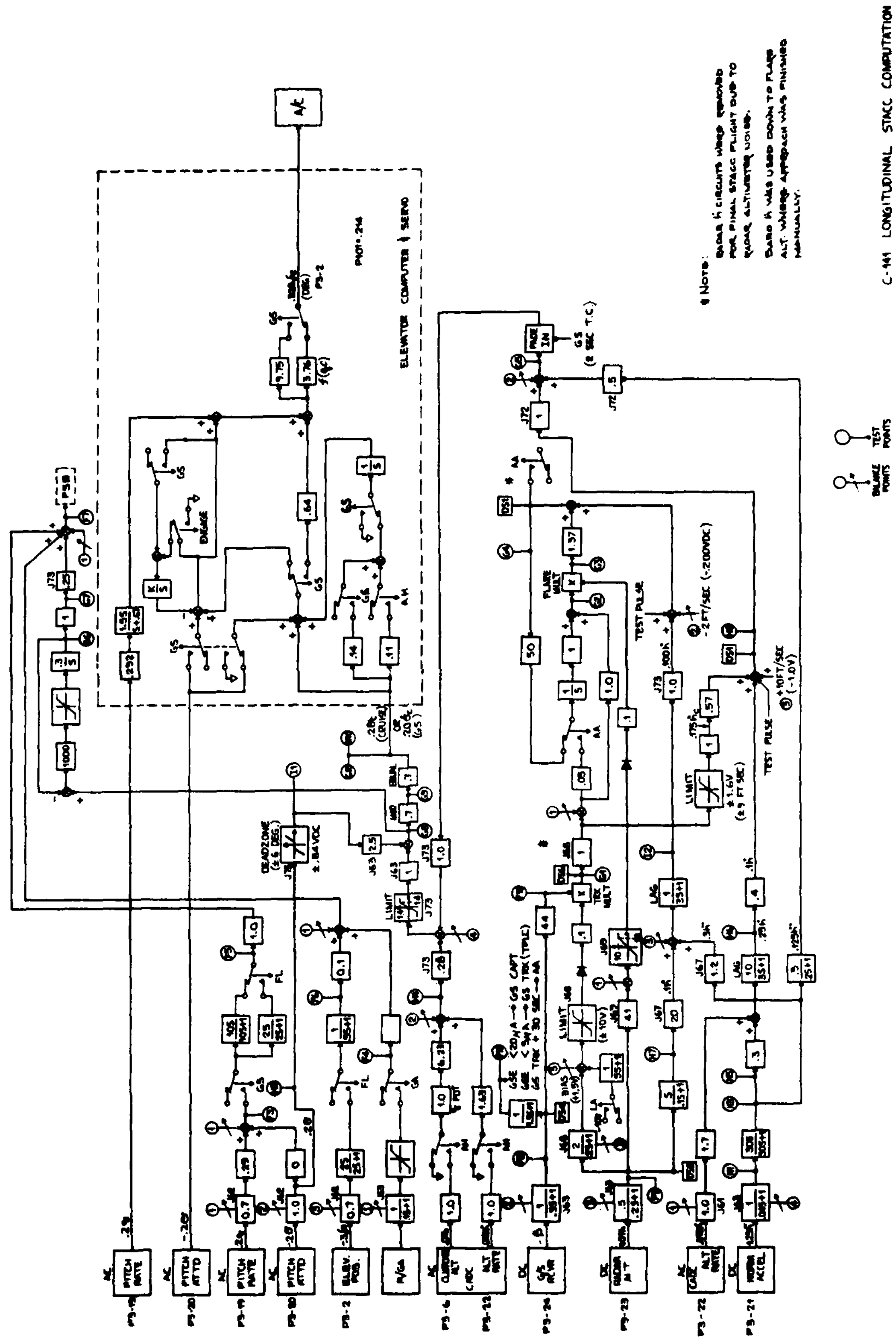


FIGURE 6 Longitudinal STACC Computation

SYSTEM PERFORMANCE MODEL

The modeling approach adopted in this program was used for both the reliability and safety analyses. It accommodates the total systems configuration by partitioning the system into a set of time/function related modules.

The basic airborne control system is composed of a dual automatic system backed up by a manual system. It presented command information for vertical and lateral control of the aircraft by displaying the information on the pilot and copilot attitude director indicators. The fault monitoring capability of the system provides coverage of failures occurring in the sensitive (or critical) functions of the dual automatic operation. If a detectable failure occurs in the dual automatic system, the affected axis (vertical or lateral) is disengaged and the pilot is alerted of the failure. From a functional standpoint, the pilot may decide to manually fly the disengaged axis or completely disengage the automatic system. However, in Category III weather, procedures require that an immediate go-around maneuver be initiated in response to a detected system failure.

From a safety viewpoint, only that portion of the landing sequence representing a significant safety hazard had to be modeled in the analysis. This critical portion of the landing sequence is shown diagrammatically in Figure 7. It may be observed that the critical landing sequence is divided into four discrete and contiguous time intervals: (1) flare engage to decrab engage, (2) decrab engage to touchdown, (3) touchdown to wheel spin-up and (4) rollout.

Guidance signals from the ground based instrument landing system (ILS) were provided via a localizer radio frequency beam for lateral control and via a glide slope radio frequency beam for vertical control. The localizer and glide slope transmitting systems are physically separate and independent from each other.

The first logical partition of our systems model was to separate the vertical and lateral control functions for the airborne control system and the ILS. Once these partitions were defined, the specific system functions and crew procedures

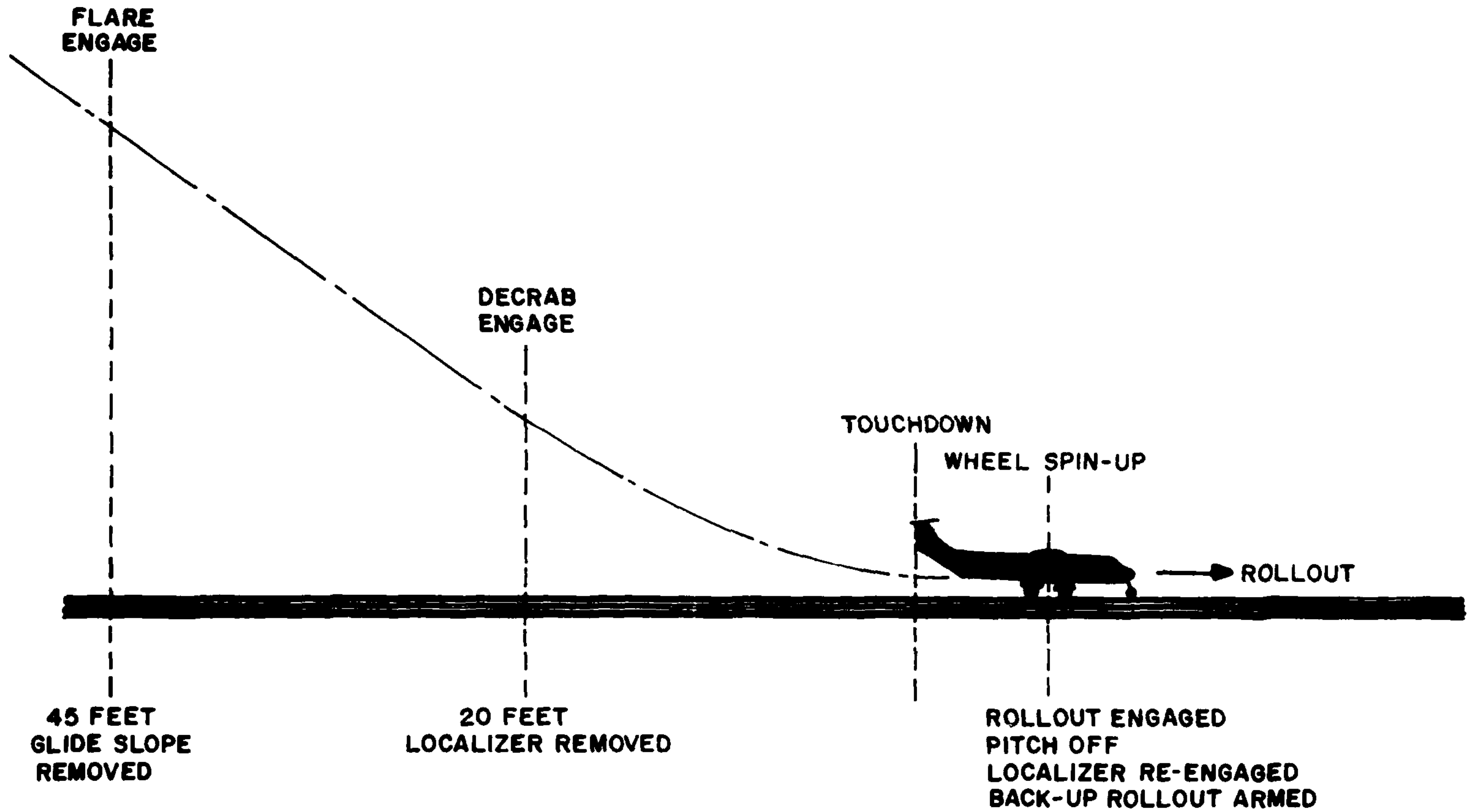


FIGURE 7 Landing Sequence

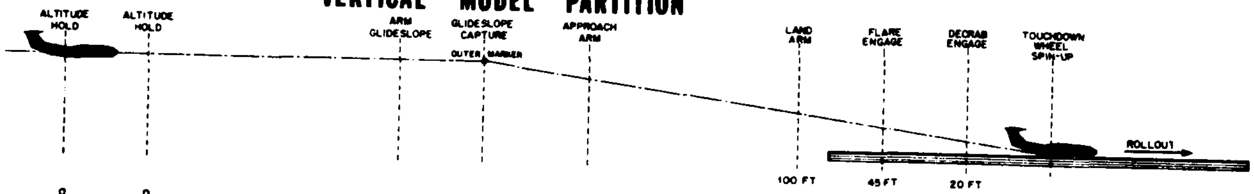
were related to their respective partition. The actual process of relating system functions, procedures, and equipments to the partitioned lateral and vertical axes was used to analyze the approach and landing sequence in considerable detail. The results of this analysis revealed that certain equipments or functions were only used during specific segments of the landing sequence, while other equipments were essential during the entire approach and landing sequence.

The equipment utilization for the vertical and lateral partitions is illustrated in Figures 8 and 9 respectively. This equipment utilization information was integrated to represent the total equipment utilization or operation for the airborne control system as a function of aircraft progression through the landing sequence.

The next step in the analysis sequence was to develop a mathematical model to represent the reliability of the airborne control system and procedures. Essential to this model was a compilation of the equipment failure characteristics.

The majority of the equipment in the airborne control system has had extensive fleet exposure. Failure rate data for the standard C-141 equipment was obtained from C-141 shop maintenance records for a one year period from May 1974 to April 1975. Wilcox (800C and 806C) ILS receivers, identical to those used on the test aircraft, are currently being used on the C-5 and their failure rate data was obtained from the C-5 fleet maintenance records for a six month period from April 1975 through September 1975. It is assumed that by using a sufficient data base, the effect of time lags, between flight-line remove and replace actions and shop repair actions, on maintenance records could be minimized. Failure rate information for the Sperry 350B Attitude Director Indicators, Litton LTN-51 Inertial Platforms, and the Collins 51RV2B ILS Receivers was not readily available from military fleet maintenance records and was obtained from the respective manufacturers. The custom-built Category III Adapter and Runway Distance Remaining Indicator failure rate data was obtained from the flight log and maintenance records for the test aircraft. Failure rate data for the Simplified Terminal Area Control Computer (STACC) was estimated from similar equipment.

VERTICAL MODEL PARTITION



	ALTITUDE HOLD	ALTITUDE HOLD	ARM GLIDESLOPE	GLIDESLOPE CAPTURE	APPROACH ARM	LAND ARM (100 FT)	FLARE ENGAGE (45 FT)	DECRAB ENGAGE (20 FT)	TOUCHDOWN WHEEL SPIN-UP
ATTITUDE DIRECTOR INDICATOR	o	o	o	x	x	x	x	x	o
AFCS CONTROL PANEL	x	x	x	x	x	x	x	x	x
AFCS COUPLER	x	x	x	x	x	x	x	x	o
AFCS SERVO (ELEVATOR)	x	x	x	x	x	x	x	x	o
AUTO-THROTTLE COMPUTER	o	o	o	x	x	x	x	x	o
CENTRAL AIR DATA COMPUTER	x	x	x	x	x	x	x	x	x
CATEGORY III ADAPTER	x	x	x	x	x	x	x	x	x
ELEVATOR COMPUTER	x	x	x	x	x	x	x	x	o
FLIGHT DIRECTOR COMPUTER	o	o	o	x	x	x	x	x	o
FLARE COMPUTER	o	o	o	o	o	x	x	x	o
GLIDESLOPE RECEIVER	o	o	x	x	x	x	o	o	o
INERTIAL NAVIGATION SYSTEM	x	x	x	x	x	x	x	x	x
MASTER CAUTION CONTROLLER	o	o	o	o	x	x	x	x	o
NAVIGATION SELECTOR	x	x	x	x	x	x	x	x	x
PITCH ATTITUDE GYRO	o	o	o	o	x	x	x	x	x
PITCH RATE GYRO	x	x	x	x	x	x	x	x	x
RADAR INDICATOR	o	o	o	o	x	x	x	x	o
RADAR RECEIVER TRANSMITTER UNIT	o	o	o	o	x	x	x	x	o
ROTATE AND GO AROUND COMPUTER	o	o	o	o	o	o	o	o	o
TEST PROGRAMMER & LOGIC COMPUTER	o	o	o	x	x	x	x	x	x

FIGURE 8 Vertical Mode Partition

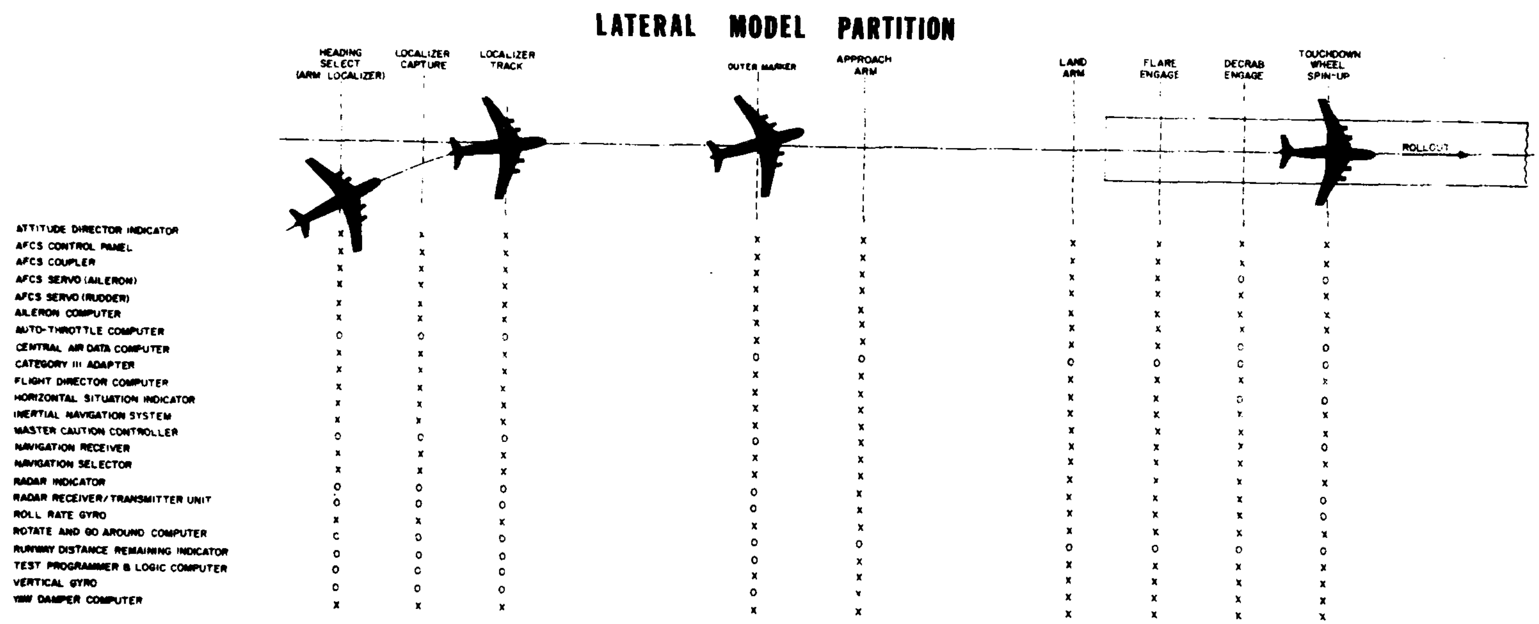


FIGURE 9 Lateral Mode Partition

The first generation calculations of the failure rates for the equipment was at the so-called box level with items such as accelerometers, transmitters, etc., which furnish pertinent information to the various pieces of equipment, included in their respective box level calculations. This box level failure rate information is presented in Table 2. In most instances the box level failure rates were apportioned down to the so-called card level (second generation) by evaluating the on-equipment maintenance actions with respect to the card level shop repairs. An itemized summary of the card level failure rates is included in Appendix A.

A few basic assumptions regarding the equipment failure rates were invoked. First of all, each piece of equipment was assumed to be independent and, secondly, possess a constant hazard rate. The constant hazard rate assumption implies an exponential distribution of inter-failure times (or a Poisson process) and is considered very common place for electronic type equipment.

Table 2

EQUIPMENT FAILURE RATE INFORMATION

Equipment	Failure Rate (failures/hour)	MTBF (hours)
AFCS Aileron Servo	0.000366	2732.240
AFCS Control Panel	0.001584	631.305
AFCS Coupler	0.006054	165.180
AFCS Elevator Servo	0.000126	7936.508
AFCS Rudder Servo	0.002348	425.894
Aileron Computer	0.002773	360.620
Attitude Director Indicator	0.009636	103.778
Automatic Throttle Computer	0.001396	716.332
Category III Adapter	0.008895	112.423
Central Air Data Computer System	0.024055	41.571
Elevator Computer	0.003641	274.650
Flare Computer	0.001558	641.849
Flight Director Computer	0.001017	983.284
Glideslope Receiver	0.002003	499.251
Horizontal Situation Indicator	0.002910	343.643
Inertial Navigation System	0.000968	1033.058
Master Caution Controller	0.001596	626.566
Navigation Receiver	0.000678	1474.926
Navigation Selector	0.001368	730.994
Pitch Attitude Gyro	0.002621	381.534
Pitch Rate Gyro	0.000650	1538.462
Radar Indicator	0.002028	493.097
Radar Receiver Transmitter Unit	0.004262	234.682
Roll Rate Gyro	0.000650	1538.462
Rotate and Go-Around Computer	0.002927	341.647
Runway Distance Remaining Indicator	0.005438	183.900
Simplified Terminal Area Control Computer	0.005059	197.668
Test Programmer and Logic Computer	0.002452	407.830
Vertical Gyro	0.002621	381.543
YAW Damper Computer	0.003289	304.044

A few words about each assumption are in order. By assuming a Poisson process, the individual equipment failure rates (λ) and hazard rates ($Z(t)$) are essentially constant and equivalent. Therefore, the mean time between failures (MTBF) and the reliability function ($R(t)$) for each piece of equipment can be described as follows:

$$R(t) = \exp\left[-\int_0^{\tau} Z(\xi)\, d\xi\right]$$
$$= e^{-\lambda t}$$

where t = operational time interval

and $\text{MTBF} = \int_0^{\infty} R(t)\, dt = \int_0^{\infty} e^{-\lambda t}\, d\tau$

$$= \frac{1}{\lambda}$$

Earlier it was pointed out that procedures required a go-around in response to a detected system failure during a Category III weather landing. This means that the failure of a single piece of required operational equipment would cause the landing sequence to be aborted and a go-around initiated. Now when this requirement is examined with the assumption of equipment independency, it is evident, from an essentiality standpoint, that we are modeling a series structure. The reliability or probability of successfully completing the landing sequence was represented as follows:

$$R(t) = \prod_{i=1}^{n} e^{-\lambda_i t} = e^{-(\sum_{i=1}^{n} \lambda_i)t}$$

where λ_i = failure rate for equipment (i)

and t = operational time interval.

The Poisson process has an additional feature relative to it's "lack of memory". Specifically, since the hazard rate is constant, each piece of equipment is just as likely to fail at time 't' as it is to fail at time 't' + delta 't'. This effectively gives license to reset time to zero after each confirmation of successful performance. In our model the first comprehensive indication that <u>all</u> systems are operational occurs at the completion of the diagnostic pre-land test and is annunciated at the approach arm. Prior to the

pre-land test annunciation, selected latent failures on portions of the operating but non-functional equipment could be detected but not get annunciated. Therefore, for these reasons the model validation process was restricted to the approach and landing sequence from approach arm through rollout.

SECTION IV

GROUND SYSTEM DISCUSSION *

As mentioned under System Definition and Configuration, the flight test program used a Category II ILS ground facility to gain Category III experience by adding additional automatic guidance capabilities below 100 feet to the aircraft control system. The study, however, included modeling a Category III ILS with Traveling Wave Antenna and examined two specified techniques for redundant real-time integral monitoring.

A Category III ILS provides aircraft with guidance information from the coverage limit of the facility to and along the surface of the runway. The system analyzed had operational performance of Category III, that is, operation with no decision height limitation. Initially, the system was used in Category IIIA operations in which use was made of external visual references during the final phases of landing with runway visual range (RVR) of not less than 700 feet. As the flight test program progressed, both Category II and Category III facilities were used at various locations throughout the country. Fourteen landings were made in reported RVRs of zero.

The ILS basically consists of two separate stations, the localizer and the glideslope. In addition to these stations, a central point for station control and the display of station status exists at the control tower. Up to three marker beacons are also used in a typical ILS installation. The localizer provides guidance in the horizontal plane and the glideslope station provides guidance in the vertical plane.

The localizer antenna group radiates two VHF carriers, each amplitude modulated by 90 and 150 Hz and with both carrier frequencies within a particular VHF channel. The radiation field pattern of one carrier produces a course sector which radiates $\pm$ 10 degrees either side of the runway center line and the other produces a clearance radiation field pattern outside that sector to $\pm$ 60 degrees from the course line.

The glideslope station produces a UHF composite field radiation pattern that provides a straight line descent path in the vertical plane and a clearance pattern to provide low angle coverage. Both carriers (course and clearance)

are within a particular UHF channel. Again, 90 and 150 Hz tones are used with the 150 Hz tone predominating below the path angle and the 90 Hz tone predominating above the path angle. The low angle clearance, radiated by the second carrier, is provided by a 150 Hz tone.

There are two transmitter sections incorporated into the localizer station. One transmitter is designated as the main transmitter; the other is designated the standby transmitter. The output signals from the main and standby transmitting units are routed to a changeover and test unit where transmitter transfer capabilities are accomplished. The signals received from the control unit determine which transmitter operates into the antenna, the main or standby. When the main transmitter is connected to the antenna system, the standby transmitter operates into dummy loads. When the standby unit is connected to the antenna system, the main unit is turned off. Within the changeover and test unit, there exists circuitry for use in monitoring standby transmitter parameters.

The glideslope station is very similar to that of the localizer. Some major differences are:

(1) The glideslope does not possess either a far field monitor or an identification unit/monitors.

(2) The glideslope antenna depends on the ground plane to form the radiation pattern.

(3) Triplicate near-field monitors are used for the glideslope.

(4) No shutdown alert warning signal is provided.

The changeover and test unit provides the same function as that of the localizer; transfer transmitter signals of the main and standby unit into either the antenna systems (including distribution circuits) or dummy loads. Also within the changeover and test unit, there exists circuitry for monitoring the standby transmitter parameters.

The far-field monitor has its own alarm processing circuitry to minimize the quantity of telephone lines needed for remote transmission. Each far field monitor channel provides two alarm outputs, a Category III alarm and a Category II alarm. The difference between these two alarm outputs is merely in tolerance limits.

In order to know the true integrity of the signal in space at all times, integral monitoring along with localizer far-field and glideslope near-field detectors, are used. Out-of-tolerance radiation must be limited without limiting system performance.

Integral monitoring is accomplished by use of detectors which sample the localizer and glideslope radiation in very close proximity to each excited element. These proximity detectors are thus insensitive to the effects of environmental conditions or aircraft overflights. The detected signals are then combined to correspond to the signal received by the approaching aircraft in the far-field of the transmitting antenna. Glideslope near-field detectors have been retained for monitoring radiated signals, but are considered to serve only a secondary role. The localizer far-field monitor will guard against substandard system perfomance from major obstructions moving in front of the localizer structure. Monitor redundancy is used to achieve the desired level of monitor reliability.

Two specified schemes of monitoring logic were analyzed for safety/reliability and risk. As shown in Figure 10, the monitoring process demodulates the monitor inputs into three components:

(1) Radio Frequency Energy (RF)

(2) Difference in Depth Modulation (DDM), and

(3) Sum of Depth Modulation (SDM)

Within the monitoring system, each of these components is compared with a standard established by ICAO and the FAA. A measured quantity outside the set boundary conditions will result in logic of "1" to the central control indicating an "out-of-tolerance condition".

Scheme I shows the monitored parameters (RF, DDM, SDM) and their logic levels fed to a NAND gate within each of three integral monitor boxes. The outputs of each of these three NAND gates are compared within the voter wherein at least 2 of the three must be "good".

In Scheme II, the three components (RD, DDM, SDM) from each of three integral monitors are not fed to a NAND gate but are sent to a voter where at least 2 of the three outputs of each must be correct.

Figure 11 presents the signal flow diagram for the monitored information when the main localizer transmitter radiates into the antenna. Corresponding reliability diagram, along with the associated reliability equation and attendant failure rates are presented in Figure 12. Both of these are for Scheme I.

The analogous localizer information for Scheme II is in Figure 13: the corresponding reliability diagram, equations and failure rates are given in Figure 14.

Analogously, the glideslope information for Scheme I is given in Figure 15 and Figure 16.

Under the assumption of a constant hazard function and independence of failure rates, reliabilities were calculated using a double precision computer program. The analysis showed Scheme I to be preferred with scheduled preventative maintenance: without such maintenance, Scheme II would, after a period of time, have a higher reliability. Both ensure overall reliability and safety.

*Note: Above information extracted from Mathematical Modeling of Monitoring Concepts by Fuchs and Fileccia, 1975.

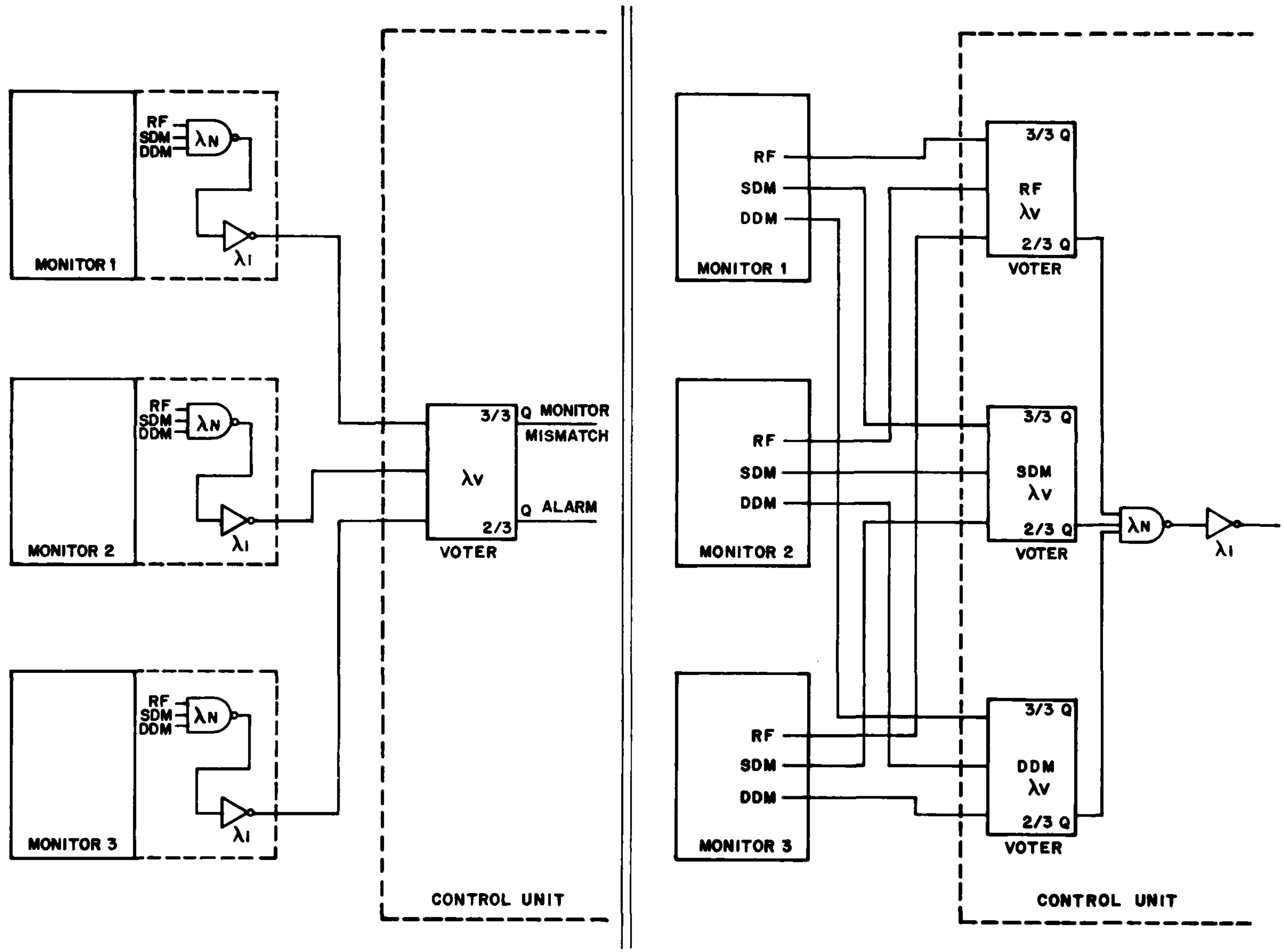


FIGURE 10 Monitor Logic

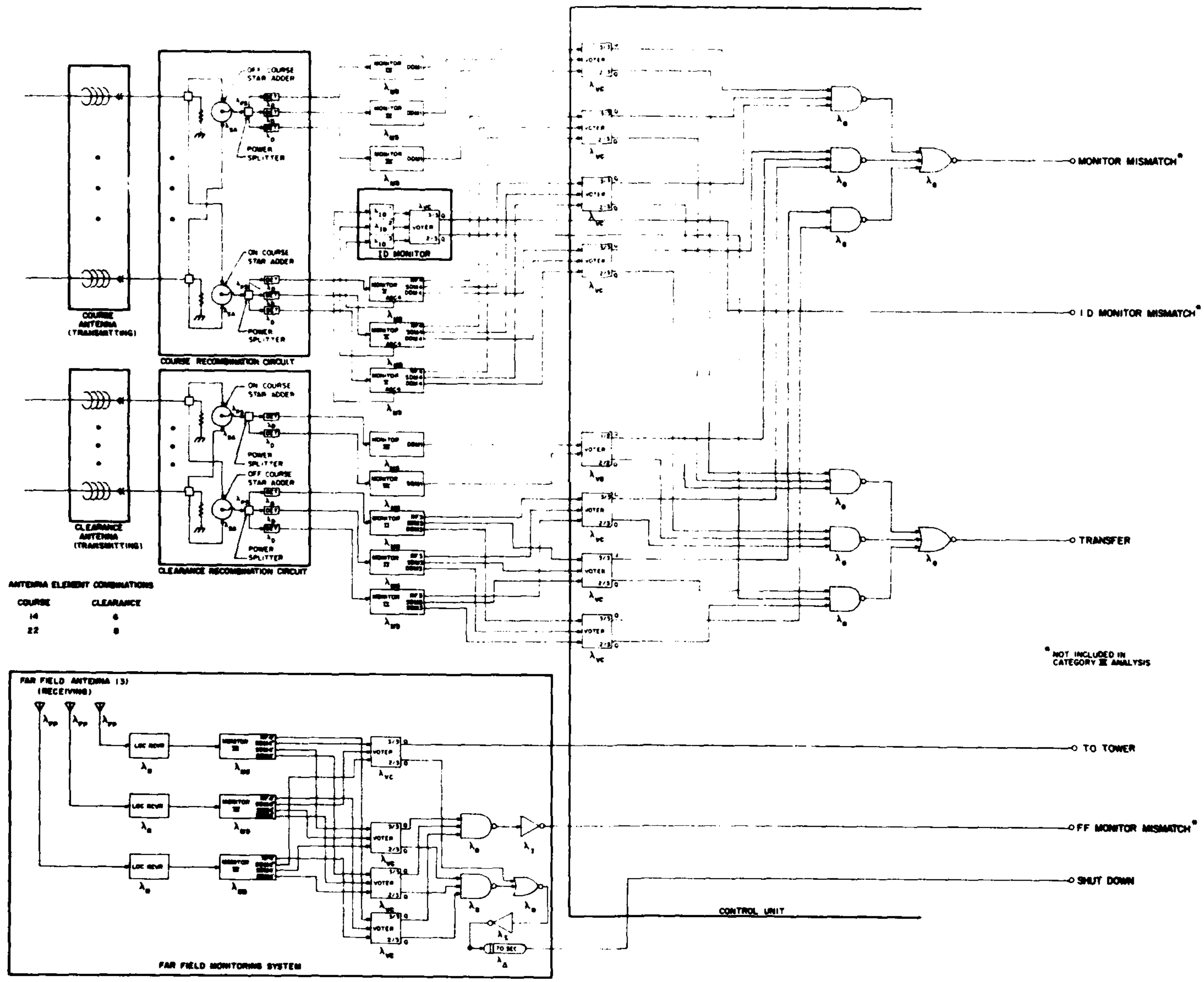
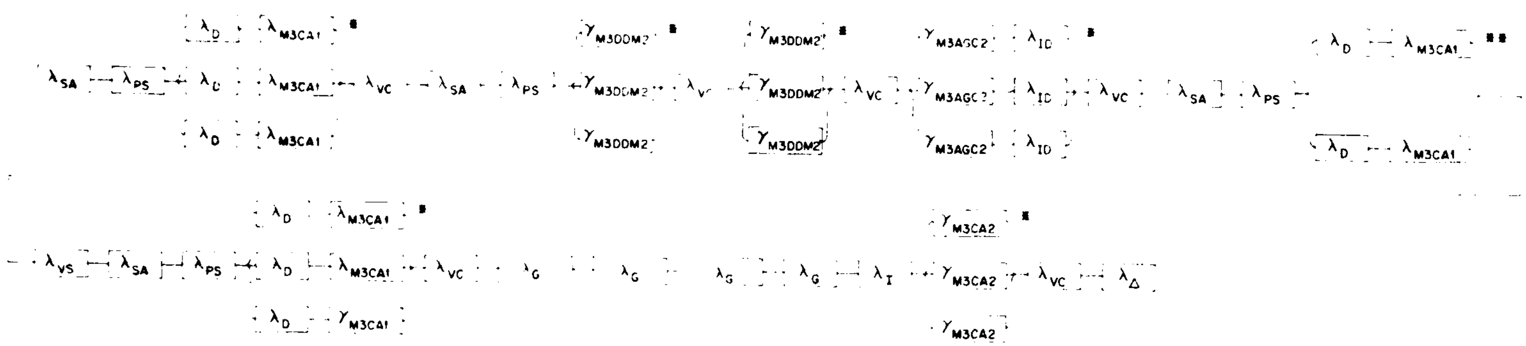


FIGURE 11 Schema I - Localizer Monitoring



* AT LEAST 2 OUT OF 3

** BOTH MUST FAIL

$$R(t) = \left[e^{-t(4\lambda_{SA} + 4\lambda_{PS} + 5\lambda_D + 5\lambda_{M3CA1} + \lambda_\Delta + 2\gamma_{M3DDM2'} + 2\gamma_{M3AGC2} + 2\lambda_{ID} + 6\lambda_{VC} + 2\gamma_{M3CA2} + 2\gamma_{M3DDM2} + \lambda_I + 4\lambda_G + \lambda_{VS})}\right] \cdot \left[3-2e^{-t(\lambda_D + \lambda_{M3CA1})}\right] \cdot \left[3-2e^{-t(\gamma_{M3DDM2'})}\right]$$

$$\cdot \left[3-2e^{-t(\gamma_{M3DDM2})}\right] \cdot \left[3-2e^{-t(\gamma_{M3AGC2} + \lambda_{ID})}\right] \cdot \left[2-e^{-t(\lambda_D + \lambda_{M3CA1})}\right] \cdot \left[3-2e^{-t(\lambda_D + \lambda_{M3CA1})}\right] \cdot \left[3-2e^{-t(\gamma_{M3CA2})}\right]$$

λ_{M3}	=	100.0×10^{-6}	λ_{VS}	=	2.0×10^{-6}	γ_{M3CA2}	=	$0.8(\lambda_{FP} + \lambda_R + \lambda_{M3})$	= 85.68×10^{-6}
λ_{M3CA1}	=	100.0	λ_Δ	=	5.0	γ_{M3AGC2}	=	$0.20(\lambda_D + \lambda_{M3})$	= 20.2
λ_{PS}	=	0.1	λ_D	=	1.0	$\gamma_{M3DDM2'}$	=	$0.2(\lambda_{FP} + \lambda_R + \lambda_{M3})$	= 21.42
λ_R	=	1.0	λ_{FP}	=	0.1	γ_{M3DDM2}	=	$0.80(\lambda_D + \lambda_{M3})$	= 80.8
λ_{SA}	=	0.1	λ_G	=	1.0				
λ_{VC}	=	5.0	λ_I	=	0.1				
			λ_{ID}	=	6.0				

FIGURE 12 Reliability Analysis Schema I

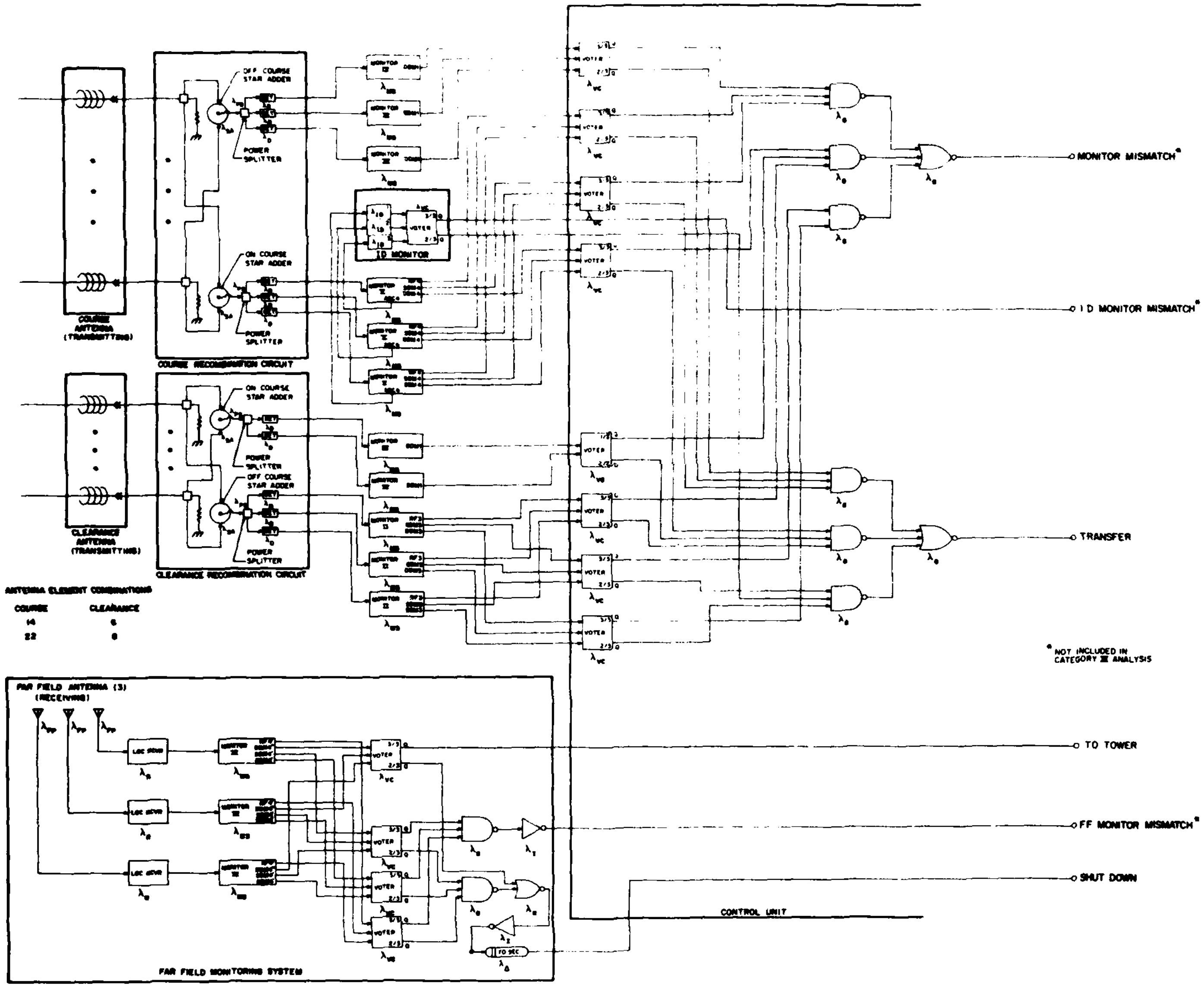
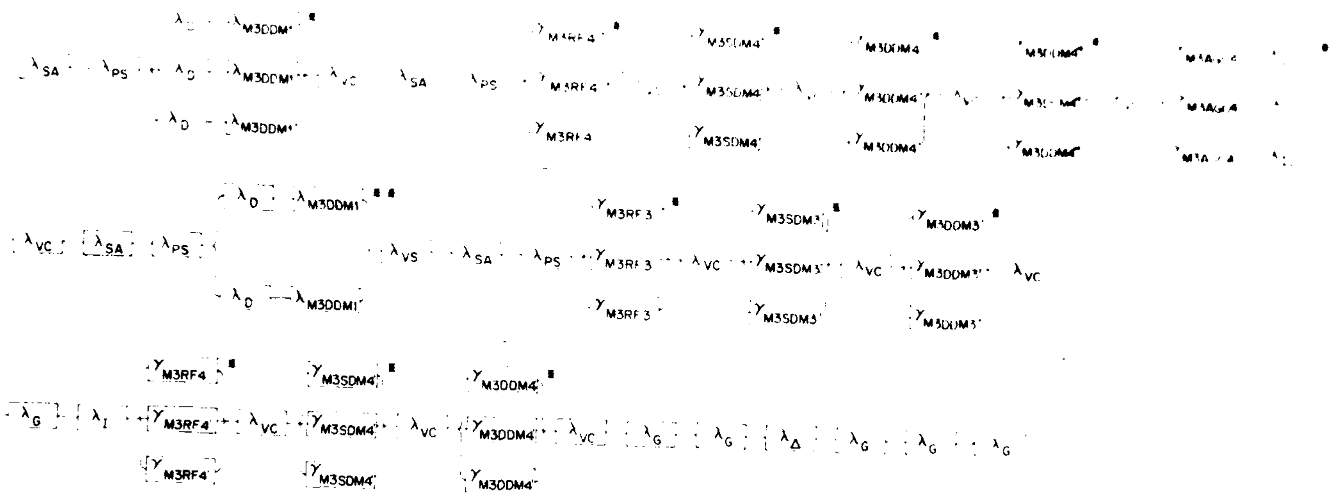


FIGURE 13 Localizer Monitoring Schema II



* AT LEAST 2 OUT OF 3

** BOTH MUST FAIL

$$R(t) = \left[e^{-t(4\lambda_{SA} + 4\lambda_{PS} + 12\lambda_{VC} + \lambda_{VS} + 2\gamma_{M3DDM4} + 6\lambda_{G} + \lambda_{I} + \lambda_{\Delta} + 3\lambda_{D} + 2\lambda_{ID} + 3\lambda_{M3DDM1} + 2\gamma_{M3RF4} + 2\gamma_{M3SDM4} + 2\gamma_{M3DDM4} + 2\gamma_{M3RF4} + 2\gamma_{M3AGC4} + 2\gamma_{M3RF4} + 2\gamma_{M3SDM4} + 2\gamma_{M3DDM4})}\right]$$

$$\cdot \left[e^{-t(2\gamma_{M3SDM4} + 2\gamma_{M3DDM4})}\right] \cdot \left[3 - 2e^{-t(\lambda_{D} + \lambda_{M3DDM1})}\right] \cdot \left[3 - 2e^{-t(\gamma_{M3RF4})}\right] \cdot \left[3 - 2e^{-t(\gamma_{M3SDM4})}\right] \cdot \left[3 - 2e^{-t(\gamma_{M3SDM4})}\right] \cdot \left[3 - 2e^{-t(\gamma_{M3DDM4})}\right] \cdot \left[3 - 2e^{-t(\gamma_{M3AGC4} + \lambda_{ID})}\right]$$

$$\cdot \left[3 - 2e^{-t(\gamma_{M3RF3})}\right] \cdot \left[3 - 2e^{-t(\gamma_{M3SDM3})}\right] \cdot \left[3 - 2e^{-t(\gamma_{M3DDM3})}\right] \cdot \left[3 - 2e^{-t(\gamma_{M3RF4})}\right] \cdot \left[3 - 2e^{-t(\gamma_{M3SDM4})}\right] \cdot \left[3 - 2e^{-t(\gamma_{M3DDM4})}\right] \cdot \left[2 - e^{-t(\lambda_{D} + \lambda_{M3DDM1})}\right]$$

$\lambda_D = 1.0 \times 10^{-6}$
$\lambda_{FP} = 0.1$ "
$\lambda_G = 1.0$ "
$\lambda_I = 0.1$ "
$\lambda_{ID} = 6.0$ "
$\lambda_{M3} = 100.0$ "
$\lambda_\Delta = 5.0$ "

$\lambda_{M3DDM1} = 100.0 \times 10^{-6}$
$\lambda_{PS} = 0.1$ "
$\lambda_R = 7.0$ "
$\lambda_{SA} = 0.1$ "
$\lambda_{VC} = 5.0$ "
$\lambda_{VS} = 2.0$ "

$\gamma_{M3DDM3} = 0.4(\lambda_D + \lambda_{M3}) = 40.4 \times 10^{-6}$
$\gamma_{M3DDM4'} = 0.3(\lambda_{FP} + \lambda_R + \lambda_{M3}) = 32.13$ "
$\gamma_{M3AGC4} = 0.167(\lambda_D + \lambda_{M3}) = 16.87$ "
$\gamma_{M3DDM4''} = 0.3(\lambda_{FP} + \lambda_R + \lambda_{M3}) = 32.13$ "
$\gamma_{M3DDM4} = 0.333(\lambda_D + \lambda_{M3}) = 33.63$ "

$\gamma_{M3RF3} = 0.2(\lambda_D + \lambda_{M3}) = 20.2 \times 10^{-6}$
$\gamma_{M3RF4'} = 0.1(\lambda_{FP} + \lambda_R + \lambda_{M3}) = 10.7$ "
$\gamma_{M3RF4} = 0.167(\lambda_D + \lambda_{M3}) = 16.87$
$\gamma_{M3SDM3} = 0.4(\lambda_D + \lambda_{M3}) = 40.4$
$\gamma_{M3SDM4'} = 0.3(\lambda_{FP} + \lambda_R + \lambda_{M3}) = 32.13$
$\gamma_{M3SDM4} = 0.333(\lambda_D + \lambda_{M3}) = 33.63$

FIGURE 14 Reliability Analysis Schema II

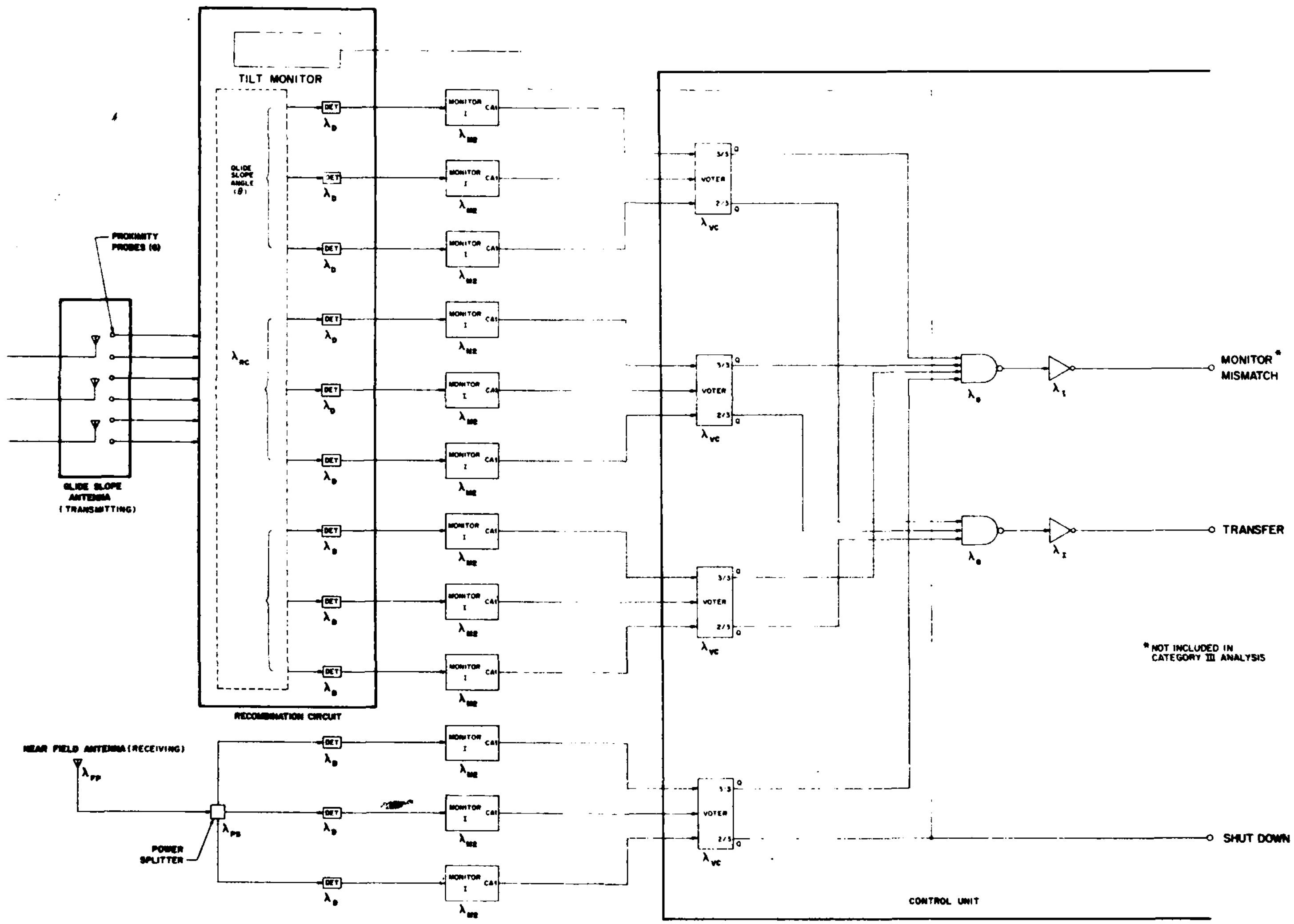
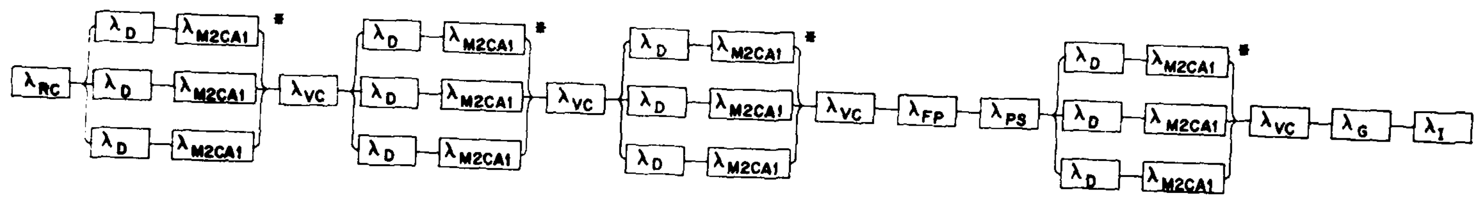


FIGURE 15 Glide Slope Monitoring - Schema I



* AT LEAST 2 OUT OF 3

$$R(t) = \left[e^{-t(\lambda_{RC} + 8\lambda_D + \lambda_{FP} + \lambda_{PS} + 8\lambda_{M2CA1} + 4\lambda_{VC} + \lambda_G + \lambda_I)}\right] \cdot \left[3 - 2e^{-t(\lambda_D + \lambda_{M2CA1})}\right]^4$$

λ_D	=	1.0×10^{-6}
λ_{FP}	=	0.1 "
λ_G	=	1.0 "
λ_I	=	0.1 "
λ_{M2CA1}	=	100.0 "
λ_{PS}	=	0.1 "
λ_{RC}	=	0.8 "
λ_{VC}	=	5.0 "

FIGURE 16 Reliability Analysis, Glide Slope, Schema I

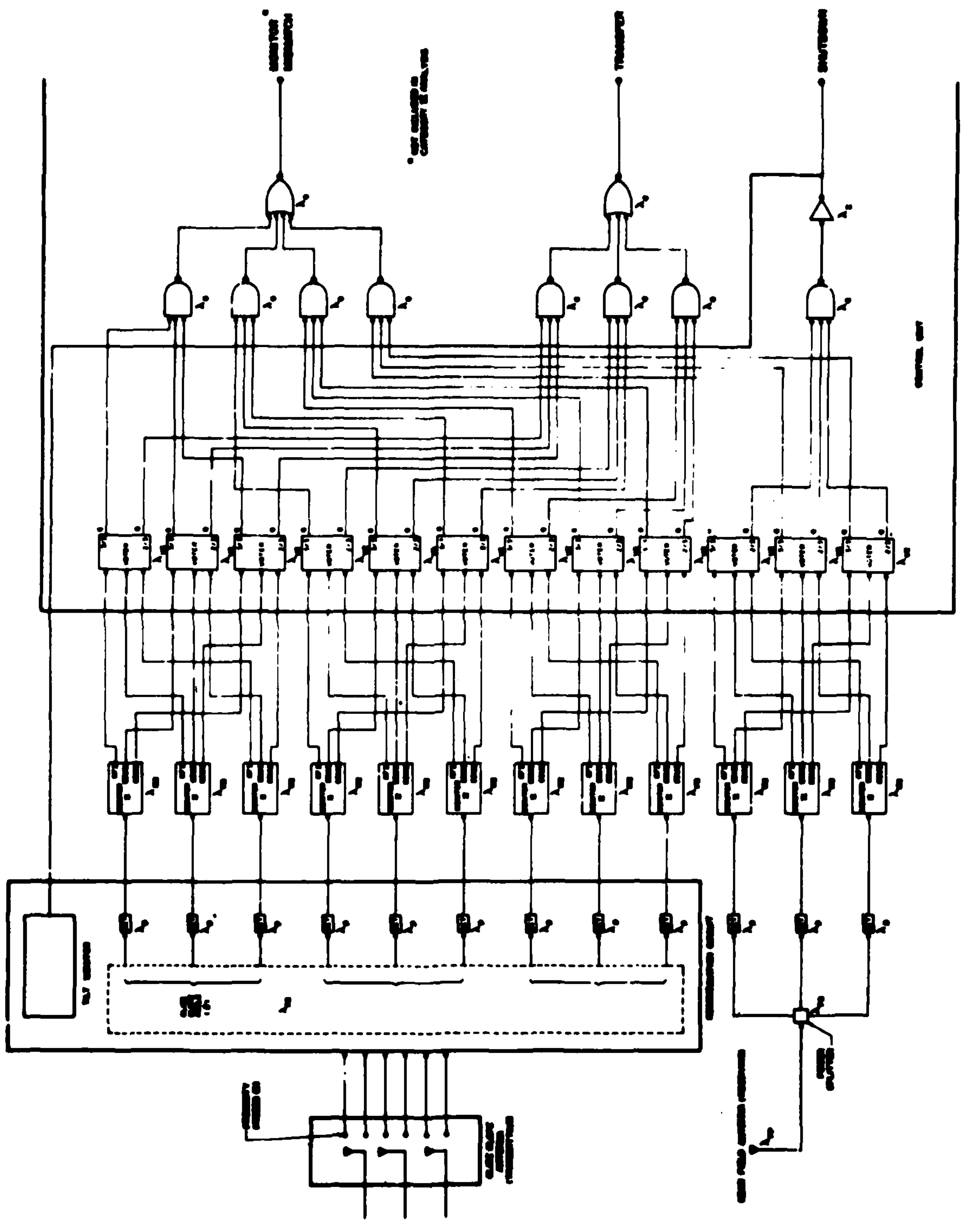
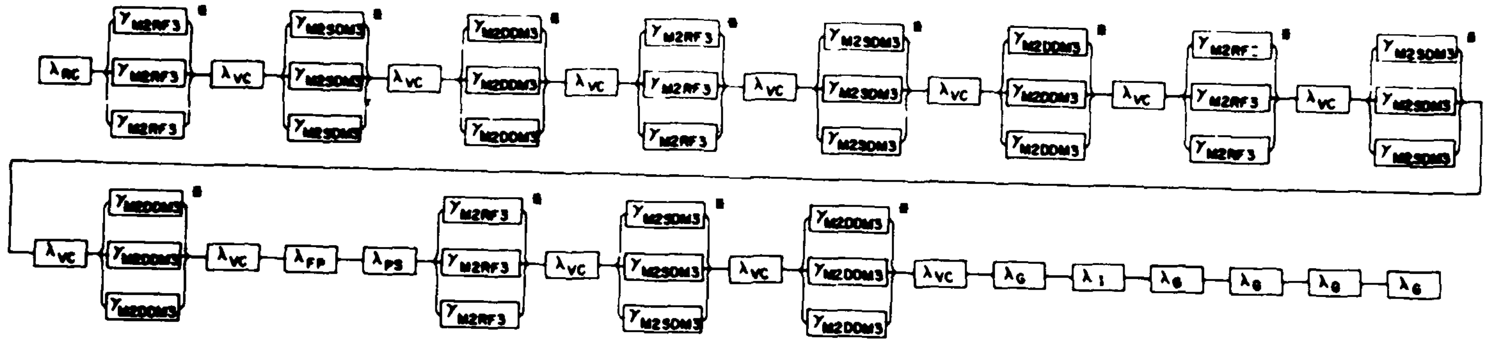


FIGURE 17 Glide Slope Monitoring - Schema II



* AT LEAST 2 OUT OF 3

$$R(t) = \left[e^{-t(\lambda_{RC} + \lambda_{FP} + \lambda_{PS} + 12\lambda_{VC} + 5\lambda_G + \lambda_I + 8\gamma_{M2DOM3} + 8\gamma_{M2RF3} + 8\gamma_{M2SDM3})}\right] \cdot \left[3 - 2e^{-t(\gamma_{M2RF3})}\right]^4 \cdot \left[3 - 2e^{-t(\gamma_{M2SDM3})}\right]^4 \cdot \left[3 - 2e^{-t(\gamma_{M2DOM3})}\right]^4$$

$\lambda_D = 10 \times 10^{-6}$

$\lambda_{FP} = 0.1$ "

$\lambda_G = 1.0$ "

$\lambda_I = 0.1$ "

$\lambda_{M2} = 100.0$ "

$\lambda_{PS} = 0.1$ "

$\lambda_{RC} = 0.8$ "

$\lambda_{VC} = 5.0$ "

$\gamma_{M2DOM3} = 0.4(\lambda_D + \lambda_{M2}) = 40.4 \times 10^{-6}$

$\gamma_{M2RF3} = 0.2(\lambda_D + \lambda_{M2}) = 20.2$ "

$\gamma_{M2SDM3} = 0.4(\lambda_D + \lambda_{M2}) = 40.4$ "

RELIABILITY ANALYSIS OF GLIDE SLOPE MONITORING SCHEME 2

FIGURE 18

SECTION V

RELIABILITY ANALYSIS

Complete reliability analyses, based on the discussion in the previous section, were formulated for the two system configurations based on the Category III adapter and the STACC. These analyses were programmed for use on the WPAFB CDC-6600 computer system. Each computer program calculated the reliability or probability of successfully completing each model segment of the landing sequence and also composite probability values for (a) the completion of the entire landing sequence from localizer capture through rollout and (b) the completion of the landing sequence subsequent to the approach arm. The details of these computer programs (including listings) are presented in Appendix B.

One of the significant features of the programs is that they provide for a sensitivity analysis capability to determine the variability effects relative to (a) the time intervals for each model segment and (b) the individual equipment MTBF values. The sensitivity analyses were based on Monte Carlo simlulation techniques which require process generators to be used to provide random sample values for the individual equipment MTBF values and landing segment time values during each iteration of the simulation. These sample values for MTBF and time were employed to determine the reliability (or probability of success) for each interval of landing sequence. By running the simulation for a large number of iterations, the sensitivity effects of MTBF and time on reliability were determined along with the inherent variability (or risk) associated with the reliability values.

At this point it is appropriate to discuss the process generators employed in this Monte Carlo simulation. The indivudual process generators for equipment MTBF were assumed to follow uniform distributions with the limits of variability set at plus and minus ten percent from the nominal values listed in Table 2. Part of the rational for choosing a uniform distribution for equipment MTBF was to accentuate the variability effects on the attendant reliability calculations. The process generators for the time intervals of the landing

sequence in Figure 7, were based on the individual time distributions from operational flight test data. This data indicated that the time distributions could be adequately represented by a series of normal distributions with the values for the mean (μ) and standard deviation (σ) listed in Table 3. The mathematics for both of these process generators is completely described in Appendix B. The completed computer programs were employed to determine the system reliability information. The reliability analyses results showing the influence of landing sequence time variability and equipment MTBF variability were determined and are presented in Table 4. The results for the system configuration based on the STACC are superior in each interval of the landing sequence. This difference was attributable to the fact that the STACC replaced several individual pieces of equipment and resulted in a lower overall system failure rate.

Additional computer runs were made to determine if landing segment time variability or equipment MTBF variability was more significant with respect to the overall system reliability. In order to accomplish this task the time and MTBF parameters were varied sequentially between zero variability and the nominal variability values previously discussed. This resulted in four sets of computer runs for each system configuration. For the system configuration based on the Category III adapter the results in Table 5 for the reliability from the approach arm to runway stop were obtained. From this data it is evident that both the time and MTBF variability affect the attendant reliability. However, the effect of MTBF variability is slightly more significant than the effect of time variability. This point is illustrative of the need to design and develop flight control systems with a minimum and controlled failure rate.

It should again be mentioned that a complete set of computer printouts are provided in Appendix B.

Table 3

TIME DISTRIBUTION DATA

Time Segment	Mean (seconds)	Standard Deviation (seconds)
localizer capture to arm glideslope	210*	—
arm glideslope to glideslope capture	30*	—
preland test	30*	—
1000 feet to 100 feet	81.54**	1.95**
100 feet to flare engage	5.35	0.42
flare engage to decrab	3.07	0.33
decrab to wheel spin-up	4.02	0.33
wheel spin-up to stop	22.73	0.53

* point estimate

** extrapolated from recorded data for 200 foot to 150 foot segment

Note: The mean and standard deviation values were obtained from recorded data for Missions 171, 175, 179, and 185.

Table 4 RELIABILITY ANALYSIS RESULTS

	Category III Adapter	STACC
Localizer Capture to Arm Glideslope		
Mean of Reliability	.9958494	.9964784
Std. Dev. of Reliability	.0000683	.0000611
Arm Glideslope to Glideslope Capture		
Mean of Reliability	.9993891	.9994794
Std. Dev. of Reliability	.0000098	.0000088
Glideslope Capture to Approach Arm		
Mean of Reliability	.9993570	.9994474
Std. Dev. of Reliability	.0000100	.0000088
Approach Arm to Land Arm (100 Feet)		
Mean of Reliability	.9978379	.9980751
Std. Dev. of Reliability	.0000377	.0000412
Land Arm (100 Feet) to Flare Engage (45 Feet)		
Mean of Reliability	.9998851	.9998733
Std. Dev. of Reliability	.0000074	.0000067
Flare Engage (45 Feet) to Decrab (20 Feet)		
Mean of Reliability	.9999203	.9999293
Std. Dev. of Reliability	.0000057	.0000048
Decrab (20 Feet) to Touchdown		
Mean of Reliability	.9998935	.9999072
Std. Dev. of Reliability	.0000054	.0000042
Touchdown to Stop		
Mean of Reliability	.9995344	.9995604
Std. Dev. of Reliability	.0000108	.0000087
Total Reliability From Approach Arm to Stop		
Mean of Reliability	.9970431	.9973469
Std. Dev. of Reliability	.0000684	.0000712
Total Reliability For Complete Model		
Mean of Reliability	.9916602	.9927685
Std. Dev. of Reliability	.0001786	.0001700

Table 5 Sensitivity Effects For Reliability Values For Interval From Approach Arm to Runway Stop (Category III Adapter System Configuration)

Landing Segment Time Variability		Equipment MTBF Variability: Zero	Equipment MTBF Variability: Ten Percent
	Zero	Mean = .9970469 Std. Dev. = .0000000	Mean = .9970363 Std. Dev. = .0000564
	Based on Operational Flight test Data *	Mean = .9970536 Std. Dev. = .0000451	Mean = .9970431 Std. Dev. = .0000684

* From Table 3

SECTION VI

MODEL VALIDATION

The only way to accurately determine if the reliability model calculations were credible was to compare them to the operational flight history for the test aircraft. Since the Category III adapter system configuration was the only one to have a large operational exposure, it was selected as the vehicle for possible model validation.

The operational data for model validation was obtained by examining the flight log and maintenance records for the test aircraft. Information on 205 automatic approach/landings made during mission 116 to 159 produced the confirmed failures listed in Table 6. This table shows that six failures occurred during the 205 approach/landings. However, since the only comprehensive confirmation of acceptable system performance is the preland test (initiated at glideslope capture and completed at Approach Arm), the exact times of failures occurring prior to the preland test could not be accurately determined. This effectively reduces the number of useable failure rate data down to 1 failure for 200 automatic approach/landings. Thus, for the 205 automatic approach/landings reviewed in the analysis, only 1 failure occurred after the Approach Arm. This can be compared to the model predicted reliability of 0.9970431 (see Table 4) or comparatively 0.61 failures for the 205 automatic approach/landings. This very close agreement between the actual and model predicted number of failures serves to demonstrate a rigorous validation of the basic reliability modeling techniques.

Table 6 AWLS Equipment Failures * (Category III Adapter Configuration)

Mission	Confirmed Equipment Failures
116	Localizer Receiver Before Glideslope Engage
129	Glideslope Receiver At Approach Arm
129	TPLC At Approach Arm
137	Coupler At Approach Arm
145	Elevator Computer At Approach Arm
145	Flare Computer At Flare Engage

* Failures were compiled for 205 Automatic Landings made during missions 116 to 159.

SECTION VII

SAFETY ANALYSIS

The safety analyses were based on a total systems concept as outlined earlier in the section on the "Systems Performance Model." A separate analysis was performed on each respective system configuration (i.e., Category III Adapter and STACC). These analyses were combined with respective reliability analysis programs for use on the WPAFB CDC-6600 computer system.

While the complete landing sequence (Figure 7 and 8) was modeled in the reliability analysis, the safety analysis modeling was restricted to that portion of the landing sequence which resulted in a significant hazard to safety for the test aircraft. After much discussion with the test pilots and systems support personnel, the general consensus was that the test aircraft could complete a successful go-around in response to any airborne control system or ILS failure prior to flare engage. It was estimated that the critical time for the go-around maneuver was approximately 3 seconds. This would allow the pilots enough time to make the required go-around control changes and arrest the sink rate of the aircraft for climb-out. Thus the safety analysis need only model the critical sequence from flare engage through rollout (see Figure 7).

From Figure 7, the critical portion of the landing sequence was composed of four separate time intervals: (1) flare engage to decrab, (2) decrab engage to touchdown, (3) touchdown to wheel spin-up, and (4) rollout. In order to understand the safety modeling approach, the basic sequence of events associated with each of the four time intervals will be examined. Prior to flare engage, the aircraft is following the guidance provided by the ground based Category III ILS. The ILS guidance is provided via a localizer radio frequency beam for lateral control and via a glideslope beam for vertical control. At the point of flare engagement the aircraft deviates from glideslope path and begins a maneuver which allows it to flare out parallel to the runway. This is accomplished by maintaining an active localizer control and disengaging the glideslope control.

The vertical guidance is then provided by the flare computers internal to the automatic flight control system. During the decrab maneuver, any heading corrections for cross winds are removed and the aircraft is aligned with the runway. This is accomplished by removing the localizer control and maintaining correct attitude control of the aircraft strictly through the use of computers internal to the automatic flight control system. The point of touchdown is self-explanatory and the aircraft control system continues to maintain active control at this point. Finally, the rollout mode is engaged at the point of wheel spin-up, which occurs when the wheels reach a speed of 60 knots. From a procedural standpoint, if wheel spin-up is not detected, an immediate go-around is initiated. For rollout, the localizer or horizontal control is re-engaged for lateral guidance purposes. If either the ground based localizer system or the aircraft localizer receivers fail between the time of localizer disengagement at decrab and localizer re-engagement at wheel spin-up, the back-up rollout mode would be engaged at wheel spin-up rather than the primary rollout mode. The back-up rollout mode uses preset heading information from the inertial navigation system (INS) rather than the localizer (Ref. 5).

From this discussion, it is evident that the safety analysis is merely an extension of the reliability analysis in terms of the basic system modeling approach with the analysis based on model segments and their respective equipment utilization factors. However, the purpose of the safety analysis was to complement the reliability analysis and breakdown the system unreliability to determine how much of this unreliability represented a hazard to the system operation. The key to breaking down this unreliability was directly tied to the identification of the minimum set of critical equipment necessary for the system to recover from an equipment failure. This equipment was identified through numerous discussions with the test pilots and system support personnel. Specifically, the critical equipment was related to the control functions required for a successful go-around maneuver and a successful rollout maneuver. If any system failure occurred prior to wheel spin-up, procedures dictate an immediate go-

around. Thus the capability for a successful go-around is crucial to the system safety prior to wheel spin-up. It was also determined that if a failure occurred after wheel spin-up, the test aircraft was required, through procedure, to stay on the ground. This makes the primary and back-up rollout capabilities crucial to system safety subsequent to wheel spin-up. The minimum sets of critical equipment, for both system configurations are presented in Figures 18, 19 and 20. In Figure 20, the set of critical equipment for a go-around maneuver is shown with three sets of guidance sensors. The dual INS is the primary set of sensors. If either one or both of the INS failed, it was assumed that there would not be sufficient time to manually switch-in either the roll and pitch gyros or the vertical gyro because of the proximity of the aircraft to the runway.

The next step in the safety analysis was to combine the calculated reliability information with failure probabilities for the respective sets of critical equipment in order to determine which combinations of single and multiple failures would represent a hazard to system safety. This was effectively accomplished by using a decision tree (or fault tree) approach where the combined effects of the airborne control system and the ground ILS were represented in composite form. The general categories of failures included in the decision tree are as follows:

Ground ILS - operational
- failed

Airborne control system - operational
- either pilot or copilot channel of information lost due to critical failure
- both pilot and copilot channels of information lost due to critical failures
- wheel spin-up not detected due to failure
- non-critical failure

The specific relationships of equipment operation and/or failure were represented for each segment of the landing sequence. Figures 21 and 22 describe the resulting decision tree developed for this analysis.

Each distinctive path through the tree represents the specific occurrence

CRITICAL EQUIPMENT FOR ROLLOUT MODE (CATEGORY III ADAPTER)

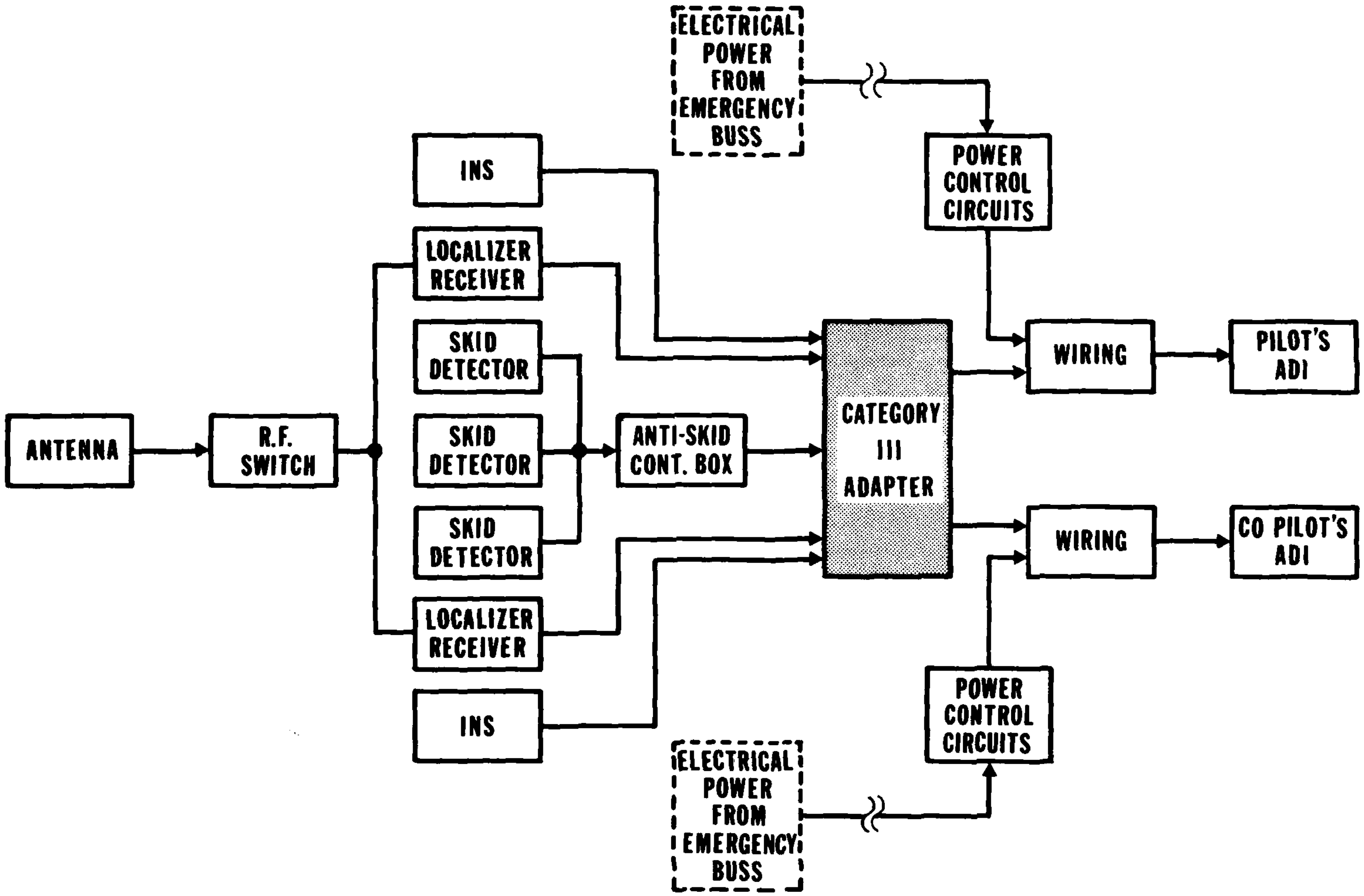


FIGURE 18a

CRITICAL EQUIPMENT FOR ROLLOUT MODE (STACC)

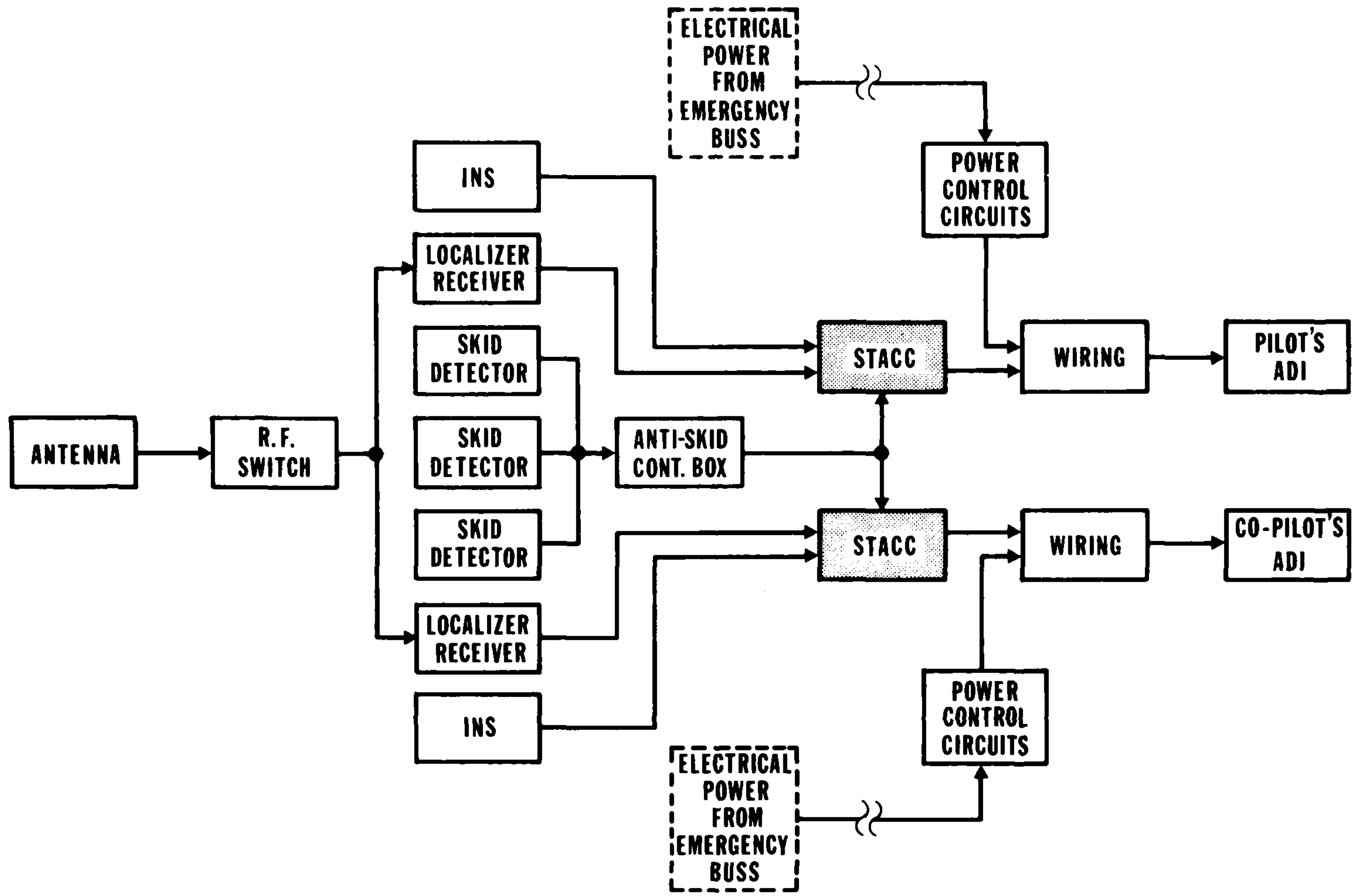


FIGURE 19

CRITICAL EQUIPMENT FOR GO-AROUND MODE

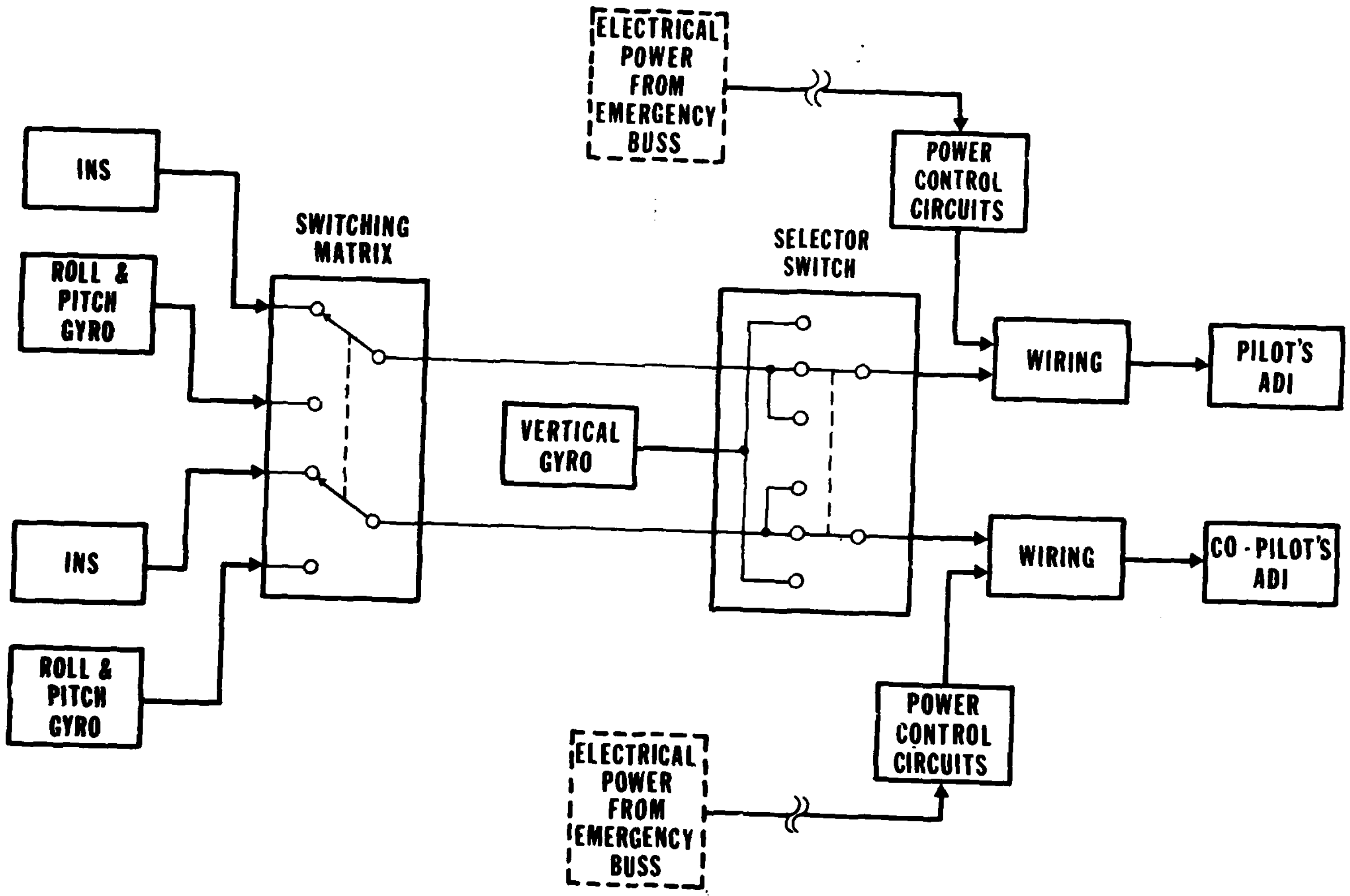


FIGURE 20

of a combination of events. The individual paths can be subdivided into a series of branches (or limb) which represent the various events. For example, the probability of successful operation (or reliability) for the total system would be represented by the bottom path through the tree.

It was the purpose of the safety analysis to determine which of the paths through the tree were hazardous to the overall system performance. These hazardous paths were represented by paths or branches which terminated in a loss of valid information to both the pilot and copilot. There was a total of seventeen such hazardous paths through the tree. Finally, the total hazard to safety for the system was obtained by summing the individual probabilities of the seventeen hazardous paths. The other paths were grouped into categories for summarization.

As stated earlier, the safety analysis computations were jointly programmed with the reliability analysis. Thus, there were safety analyses for both system configurations with each configuration having four separate computer runs to study the variant effects of equipment MTBF and landing sequence time. The safety analysis results showing the influence of landing sequence time variability and equipment MTBF variability were determined and are presented in Table 7. The results for the two system configurations are similar except for the calculated hazard to safety. Here the STACC configuration shows a hazard to safey that is approximately six orders of magnitude better than for Category III adapter configuration. This dramatic improvement in the safety calculations was attributable to the replacement of the Category III adapter, which was essentially a single point failure, with the dual redundant STACC (see Figures 18 and 19).

Upon further study of the hazards to safety, it was revealed that the original model needed some refinements. Specifically, the original model assumed that the criticality of equipment failures occurring during rollout were evenly weighted regardless of where they occurred during rollout. Said another way, the criticality of a failure at 120 knots was assumed to be equivalent to the criticality of the same failure at 20 knots. This is obviously an

DECISION TREE

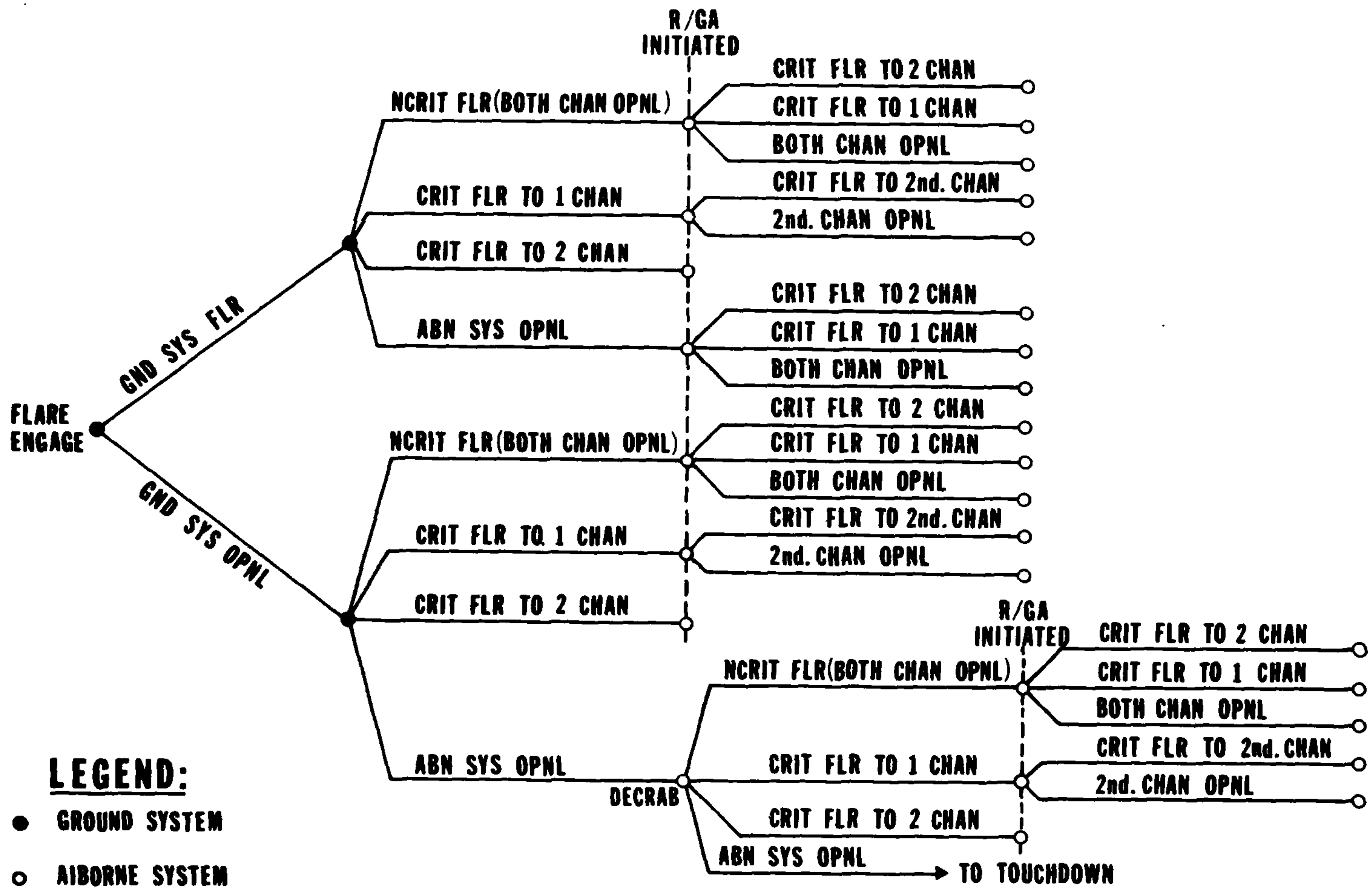


FIGURE 21

DECISION TREE (Cont.)

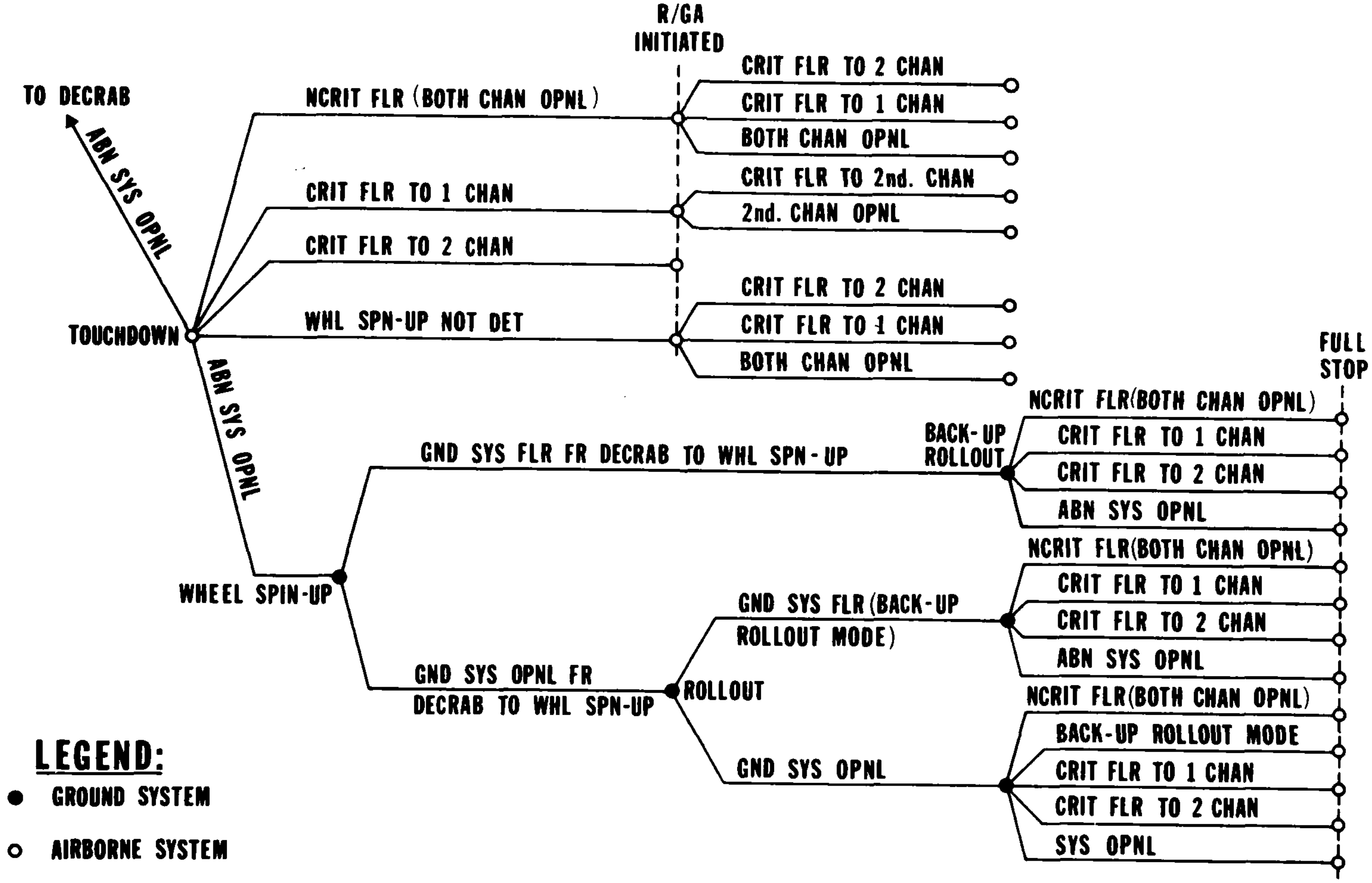


FIGURE 22

Table 7 Safety Analysis Results

	Category III Adapter	STACC
System Operational		
Probability =	.9993485	.9993971
Standard Deviation =	.0000146	.0000128
Non-Critical Failure and Successful Go-Around		
Probability =	.0002018	.0001780
Standard Deviation =	.0000081	.0000066
Critical Failure to Single Channel and Successful Go-Around		
Probability =	.0000041	.0000042
Standard Deviation =	.0000003	.0000002
Wheel Spin-up not Detected and Successful Go-Around		
Probability =	.0000005	.0000005
Standard Deviation =	2.1×10^{-8}	2.1×10^{-8}
Non-Critical Failure During Rollout		
Probability =	.0004028	.0004024
Standard Deviation =	.0000098	.0000092
Back-up Rollout Mode		
Probability =	.0000042	.0000044
Standard Deviation =	.0000002	.0000002
Critical Failure to Single Channel During Rollout Mode		
Probability =	.0000046	.0000134
Standard Deviation =	.0000002	.0000006
Localizer Failure and Successful Go-Around		
Probability =	3.5×10^{-8}	3.6×10^{-8}
Standard Deviation =	2.7×10^{-9}	2.7×10^{-8}

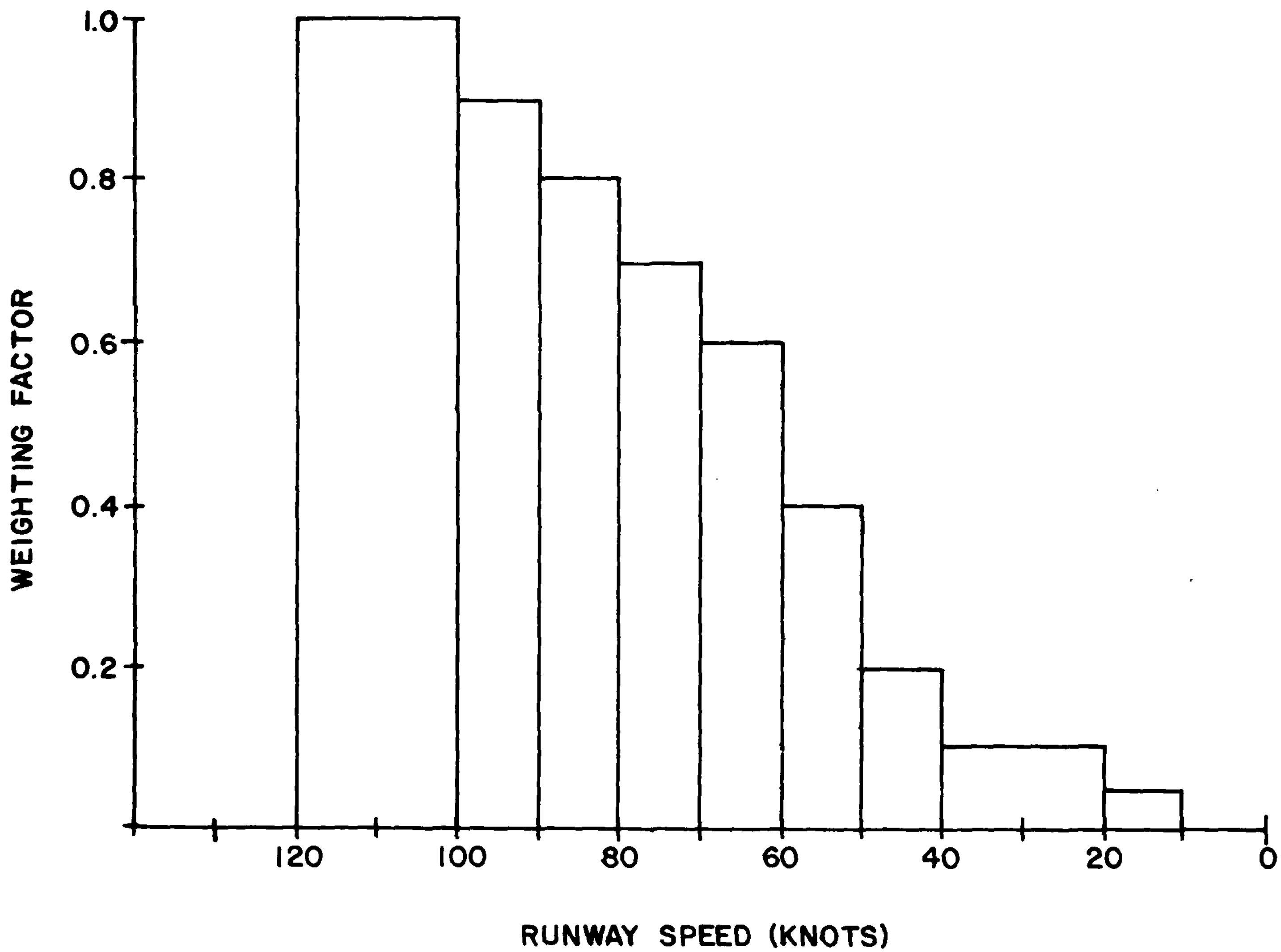
Table 7 - Cont.

	Category III Adapter	STACC
Hazard to Safety		
Probability =	.0000327	5.0×10^{-11}
Standard Deviation =	.0000015	3.9×10^{-12}

erroneous assumption. In order to achieve a more realistic modeling approach additional discussions with the test pilots and system support personnel were conducted. The results of these discussions produced two separate attenuation functions designed specifically to weight the criticality of equipment failures as a function of the aircraft ground speed and pilot visibility conditions. The first attenuation function (Figure 23) was developed for a fully automatic rollout maneuver and assumed that the pilot could not get any of the visual cues necessary for a manual takeover of the aircraft. Alternatively, the second attenuation function (Figure 24) was developed for an automatic rollout with manual assist capability. This function assumed that the pilot could indeed see the runway lighting patterns and provide a satisfactory back-up manual control capability. This second function was felt to be the more realistic because of the following statement by test pilot Major M. Lipscey. "The runway centerline lights complimented the touchdown zone lights and provided satisfactory rollout guidance for even the lowest RVR encountered during the tests. The overall ground lighting system was considered satisfactory for both a visual takeoff and landing rollout..." (Ref. 1)

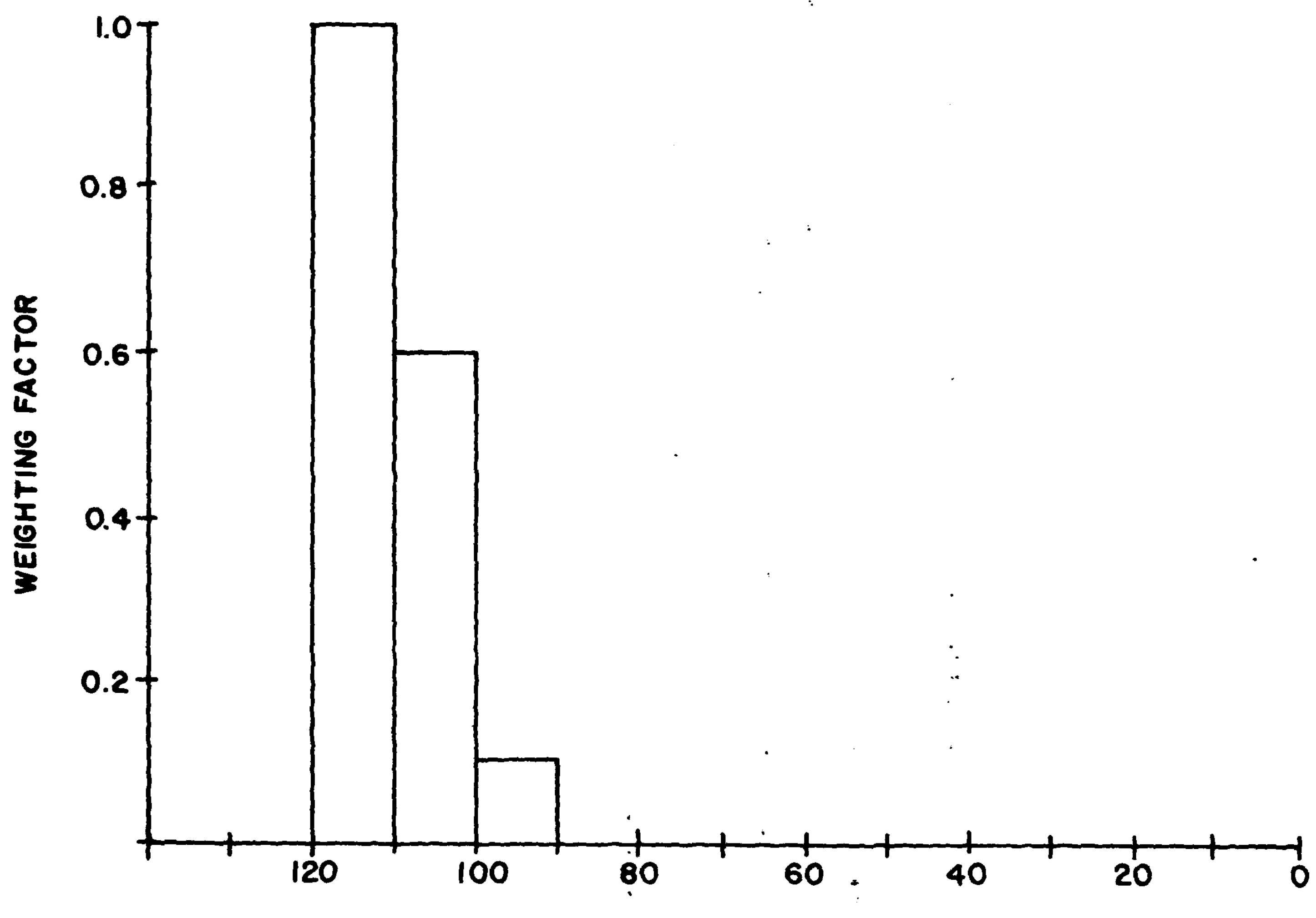
The utility of these attenuation functions was achieved by combining them with a typical runway speed profile for the test aircraft. Recorded flight data from mission 175 provided the runway speed profile information shown in Figure 25. Thus, by combining the runway speed profile with the respective attenuation functions, a time base weighting factor was defined and subsequently included in the decision tree analysis. These results are described in Table 8. It is relevant to again point out that only the hazards to safety for the rollout maneuver were attenuated. The other hazards to safety were unchanged.

From Table 8, it is evident that the safety of the STACC system configuration is again superior to the Category III adapter system configuration by approximately six orders of magnitude. The important thing to observe from this data is how attenuation functions affected the results. In all cases the hazards to safety are significantly reduced from their original calculations. For the second attenuation function (assumed to be the more realistic), the analysis



Attenuation Function - No Pilot

FIGURE 23



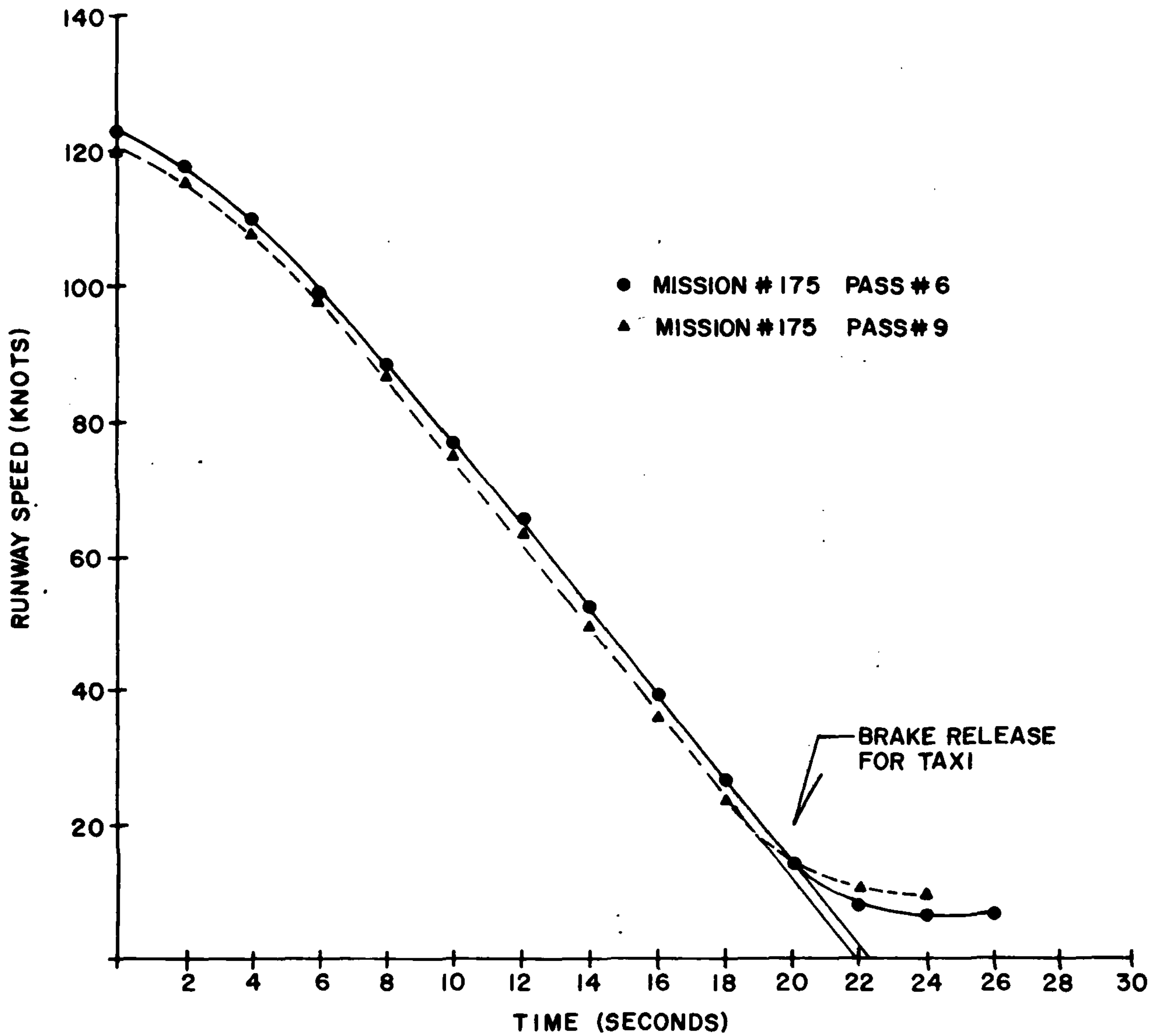
Attenuation Function Limited Visibility

FIGURE 24

predicts approximately 1 hazardous landing per 10^5 landings for the Category III adapter configuration and 1 hazardous landing per 10^{11} landings for the STACC configuration. The predicted standard deviations for these hazards are also relatively small. Thus, the variant effects of landing segment time and equipment MTBF appear to be of minor significance.

COMPARISON OF RESULTS

The results of this safety analysis were compared to accepted industry standards and experience. The Air Force specification MIL-F-9490D requires that a flight control system on a C-141-type aircraft be extremely reliable and provide a probability of aircraft loss of less than 5×10^{-7} per flight (or mission). However, when the aircraft is flown under an "environmental limit or opreational restriction" the probability of aircraft loss can be increased by a factor of not more than 30 times. This was interpreted to mean that during a Category III weather landing the probability of aircraft loss due to the flight control system should not be greater than 1.5×10^5. From Table 8, the hazards to safety, obtained by employing the second attenuation function assuming limited pilot visibility, meet the requirements outlined by MIL-F-9490D for flight control systems for both system configurations.



Runway Speed Profile

FIGURE 25

Table 8 Attenuated Safety Analysis Results *

	Category III Adapter	STACC
Original Hazard to Safety		
Probability =	.0000327	5.0×10^{-11}
Standard Deviation =	.0000015	3.9×10^{-12}
Attenuated Hazard to Safety (fully Automatic)		
Probability =	.0000200	2.3×10^{-11}
Standard Deviation =	.0000010	1.6×10^{-12}
Attenuated Hazard to Safety (Automatic/Manual Back-up)		
Probability =	.0000093	8.8×10^{-12}
Standard Deviation =	.0000006	5.9×10^{-13}

* Results show influence landing sequence time variability and equipment MTBF variability.

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1. M.J. Lipcsey, AWLS Operational Flight Test, AFFDL-TR-77-39, June 1977

2. J.S. Kozina, C-141 All Weather Landing System Engineering Support, AFFDL-TR-76-46. June 1976

3. L.S. Gephart, et al., A Systems Approach to All Weather Landings. Proceedings 1976 Annual Reliability and Maintainability Symposium, pp 25-30.

4. W.P. Fuchs and G.L. Fileccia, Mathematical Modeling of Monitoring Concepts, Proceedings 1975 Annual Reliability and Maintainability Symposium.

5. L.S. Gephart et al., Flight Control Safety: A Total Systems Approach, Proceedings 1978 Annual Reliability and Maintainability Symposium

APPENDIX A

EQUIPMENT FAILURE RATE INFORMATION

AFCS AILERON SERVO

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURES RATE (λ) FAILURES/HOUR
52ABA	Aileron Servo Actuator	1	36	0.000137
52ABB	Mount - Servo	1	0	0.000000
52ABC	Pulley	1	2	0.000008
52ABD	Cable	3	17	0.000065
52ABE	Position Transmitter	1	41	0.000156
			96	0.000366

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 2732.240 HOURS

AFCS CONTROL PANEL

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ) FAILURES/HOUR
52AAA	Control Panel	1	42	0.000160
52AAB	Indicator - AFCS Trim	1	14	0.000053
52AAD	Control Wheel Sensor	1	95	0.000361
52AAE	Auto Pilot Disengage Switch	2	1	0.000004
52AAG	Junction Box Assembly	1	0	0.000000
52AAH	Terminal Strip	10	0	0.000000
52AAJ	Diode (Rectifier)	1	3	0.000011
52AAK	Converter	1	0	0.000000
52AAL	Controller	1	2	0.000008
52AAM	Wiring	1	3	0.000011
52AAN	Mach Trim Transmitter	1	0	0.000000
52EFO	Control Panel Autopilot	1	257	0.000976
			417	0.001584

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 631.305 HOURS

AFCS COUPLER *

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ) FAILURES/HOUR
52EEA	Dual D/C, D/C Comparator	1	47	0.000179
52EEB	Limited Detector Integrator	1	107	0.000406
52EEC	Module SW. Card NR. 3	1	82	0.000311
52EED	Module SW. Card NR. 2	1	151	0.000574
52EEE	Module SW. Card NR. 1	1	163	0.000619
52EEF	Comparator	1	84	0.000319
52EEG	Comparator	1	15	0.000057
52EEH	Desensitizer	1	43	0.000163
52EEJ	Power Supply Assembly	1	279	0.001060
52EEK	Amplifier Filter	1	160	0.000608
52EEL	Detector Limiter	1	39	0.000148
52EEM	Desensitizer	1	48	0.000182
52EEN	Desensitizer	1	27	0.000103
52EEP	Detector Filter	1	29	0.000110
52EEQ	Compass Synchronizer	1	81	0.000308
52EER	Desensitizer	1	24	0.000091
52EES	Desensitizer	1	76	0.000289
52EET	Functions Assembly	1	43	0.000163
52EEU	Comparator	1	83	0.000315
56DJD	Accelerometer Vertical	1	13	0.000049
			1594	0.006054

Total Flight Hours = 263254 Hours
MTBF = $(\Sigma\lambda)^{-1}$ = 165.180 Hours
* Replaced by STACC

AFCS ELEVATOR SERVO

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ) FAILURES/HOUR
52ADA	Elevator Servo Actuator	1	20	0.000076
52ADB	Mount - Elevator Servo	1	0	0.000000
52ADC	Pulley	1	0	0.000000
52ADD	Cable	3	12	0.000046
52ADE	Clutch	1	1	0.000004
			33	0.000126

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 7936.508 HOURS

AFCS RUDDER SERVO

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ) FAILURES/HOUR
52ACA	Yaw Damper Servo Actuator	2	173	0.000657
52ACB	Mount - Yaw Damper Servo	1	0	0.000000
52ACC	Control Dual Yaw Damper	1	46	0.000175
52ACD	Gyro - Single-Axis Rate	3	399	0.001516
52ACE	Brushes	4	0	0.000000
			618	0.002348

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 425.894 HOURS

AILERON COMPUTER

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
52ECA	Power Supply Assembly	1	79	0.000300
52ECB	Comparator Assembly	1	46	0.000175
52ECC	Adapter Assembly	1	100	0.000380
52ECD	Detector Assembly	1	31	0.000118
52ECE	Module Servo Assembly	1	14	0.000053
52ECF	Pre-Amp Assembly	1	110	0.000418
52ECG	Roll CWS Assembly	1	48	0.000182
52ECH	Servo Drive Assembly	1	32	0.000122
52ECJ	Command Modifier Limiter	1	132	0.000501
52ECK	Synchronizer	1	138	0.000524
			730	0.002773

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 360.620 HOURS

ATTITUDE DIRECTOR INDICATOR

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE(λ). FAILURES/HOUR
N/A	Sperry 350B ADI	2	N/A	0.000674*
51BGD	Transmitter-Rate-of-Turn	2	738	0.002803
51BGE	Power Adequacy Indicator	2	50	0.000190
51BGG	Gyro-Displacement Roll and Pitch	2	1514	0.005751
51BGH	Transformer - Isolation	2	N/A	0.000019**
51BGJ	Wiring	1	16	0.000061
N/A	Selector Switch	1	N/A	0.000065**
N/A	Switching Matrix	1	N/A	0.000065**
N/A	Relay	2	N/A	0.000008**
			2323	0.009636

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 103.778 HOURS

* Failure Data from Manufacturer for DC-10 Fleet from September 1974 to August 1975.

** Estimated from similar equipment

AUTOMATIC THROTTLE COMPUTER

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
56BBO	Speed Trimer	1	4	0.000015
56BCA	Amplifier Power	2	49	0.000186
56BCB	Amplifier Error Integrator	1	52	0.000198
56BCC	Board Signal Processor	1	43	0.000163
56BCD	Disengage Logic Power	1	18	0.000068
56BCE	Power Supply NR. 1	1	55	0.000209
56BCF	Board Assembly Self Test	1	48	0.000182
56BCG	Flare Prog. and Rate	1	29	0.000110
56BCH	Power Supply NR. 2	1	3	0.000011
56BCJ	Elec. Comp. Assembly	1	0	0.000000
56BEO	Clutch Pack	1	39	0.000148
56BGO	Motor Generator	1	28	0.000106
			368	0.001396

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 716.332 HOURS

CATEGORY III ADAPTER *

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
N/A	CAT III Adapter	1	N/A	0.005438 *
13ACA	Touchdown Switch	4	132	0.000501
13ACB	Touchdown Relay	10	21	0.000080
13BCA	Switch NLG	1	45	0.000171
13DCA	Skid Detector	8	128	0.000486
13DCB	Control Box, Anti-Skid	1	428	0.001626
13HBN	Touchdown Control Box	1	156	0.000593
			910	0.008895

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 112.423 HOURS

** No Failure Rate Data Available - No failures occurred for 183.9 Flight Test Hours from July 1974 to June 1975 so assumed a maximum of 1 Failure per 183.9 Hours.

* Replaced By STACC

CENTRAL AIR DATA COMPUTER SYSTEM

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE(λ), FAILURES/HOUR
51AAA	CADC	2	2410	0.009155
51AAB	Airspeed Machmeter Indicator	2	726	0.002758
51AAC	Indicator-Altimeter-Rate-of-Climb	2	1668	0.006336
51AAD	Indicator True Airspeed	1	68	0.000258
51AAE	Computer Primary	1	7	0.000027
51AAF	Mach Module	1	2	0.000008
51AAG	Mechanism-Pressure Altitude	1	5	0.000019
51AAJ	Sensor Section Assy.Impact Pressure	1	0	0.000000
51AAK	True Airspeed Module	1	16	0.000061
51AAL	Impact Pressure Module	1	4	0.000015
51AAM	Amplifier - Electronic Control	1	2	0.000008
51AAN	Amplifier - Monitoring	1	0	0.000000
51AAP	Amplifier - Buffer	1	0	0.000000
51AAQ	Amplifier - Isolation	1	0	0.000000
51AAR	Power Supply Regulated	1	6	0.000023
51AAS	Relay Assy	1	1	0.000004
51AAT	Sensor-Temperature	1	2	0.000008
51AAU	Wiring	1	15	0.000057
51AAV	Amplifier-Monitor Rate	1	0	0.000000
51ABO	Amplifier-Altimeter-Rate-of-Climb	2	343	0.001303
51ACO	Amplifier-Airspeed Mach	2	139	0.000528

CENTRAL AIR DATA COMPUTER SYSTEM (cont'd)

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/ HOUR
51BAO	Pilot Static System	1	244	0.000927
51BFA	Total Temperature Probe	2	84	0.000319
51BFB	Switch-De-Ice	1	3	0.000011
51BFC	Total Temperature Indicator	1	174	0.000661
51BFD	Wiring	1	6	0.000023
51BHA	Altimeter Pressure	2	407	0.001546
			6332	0.024055

TOTAL FLIGHT HOURS = 263254 HOURS

$$MTBF = (\Sigma\lambda)^{-1} = \frac{1}{0.024055} = 41.571 \text{ HOURS}$$

ELEVATOR COMPUTER *

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
52EAA	Adapter Assembly	1	91	0.000346
52EAB	PCW Steering	1	62	0.000236
52EAC	CWS Steering	1	55	0.000209
52EAD	Comparator Assembly	1	78	0.000296
52EAE	Power Supply Assembly	1	95	0.000361
52EAF	Washout Module	1	141	0.000536
52EAG	Synchronizer	1	63	0.000239
52EAH	Preamp Filter	1	70	0.000266
52EAJ	Servo Amplifier	1	211	0.000802
52EAK	Servo Module Assembly	1	54	0.000205
52EAL	Fail Safe Amplitude Detector	1	32	0.000122
56DJC	Transmitter	1	6	0.000023
			958	0.003641

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 274.650 HOURS

* Modified for STACC

FLARE COMPUTER *

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
56BLA	Module Altitude Indicator	1	17	0.000065
56BLB	Filter and Drivers	2	57	0.000217
56BLC	Logic and Self Test	1	25	0.000095
56BLD	Module Altitude Isolation	1	4	0.000015
56BLE	Comparator	1	10	0.000038
56BLF	Power Supply	1	34	0.000129
56BLG	Regulator Assembly	1	44	0.000167
56BLH	Subassembly	1	0	0.000000
56DJD	Accelerometer Vertical	1	14	0.000053
			205	0.000779

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 641.849 HOURS

NOTE: Dual Flare Computers were used on the Test Aircraft so $\Sigma\lambda = (2)\ (0.000779)$

* Replaced by STACC

FLIGHT DIRECTOR COMPUTER *

	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
AEA	Level Detector	2	84	0.000319
AEB	Power Supply	2	16	0.000061
56AEC	Channel Latitude	2	38	0.000144
56AED	Channel Long	2	38	0.000144
56AEE	Logic Assembly	2	77	0.000292
56DJB	Transmitter	2	1	0.000004
56DJD	Accelerometer	1	14	0.000053
			268	0.001017

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 983.284

* Replaced by STACC

GLIDESLOPE RECEIVER

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
71EAA	Antenna	1	18	0.000068
71EAD	Wiring	1	9	0.000034
71GAO	Glideslope Receiver Radio	2	N/A	0.001901 *
			27	0.002003

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 499.251 HOURS

* C-5 Failure Rate Data from April 1975 to September 1975 (46 Failures during 24203 Flight hours)

HORIZONTAL SITUATION INDICATOR

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE(λ), FAILURES/HOUR
51BGK	Horizontal Situation Indicator	2	766	0.002910
			766	0.002910

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 343.643 HOURS

INERTIAL NAVIGATION SYSTEM

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
N/A	Litton LTN-51 Platform	2	N/A	0.000968*
				0.000968

$MTBF = (\Sigma\lambda)^{-1} = 1033.058$ HOURS

* Failure Rate Data from Manufacturer

MASTER CAUTION CONTROLLER

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
56DAA	Circuit Board (Control Box)	3	41	0.000156
56DAB	Circuit Board (Control Box)	2	61	0.000232
56DCO	Panel - Fault	1	33	0.000125
56DEO	Panel-Display and Warning	2	65	0.000247
56DJH	Wiring	1	2	0.000008
56DJJ	Connectors	1	8	0.000030
56DJK	Coaxial Cable	1	0	0.000000
			210	0.000798

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 626.566 HOURS

NOTE: Two Master Caution Controllers were used on the Test Aircraft so
$\Sigma\lambda = (2)\ (0.000798)$

NAVIGATION RECEIVER

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
56CDA	Antenna	1	0	0.000000
56CDB	R.F. Switch	1	3	0.000011
N/A	Collins 51RV2B Receiver	2	N/A	0.000667*
			3	0.000678

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 1474.926 HOURS

* FAILURE RATE DATA FROM MANUFACTURER

NAVIGATION SELECTOR

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE(λ), FAILURES/HOUR
51BGL	Pilot Navigation Selector Switch	1	17	0.000065
51BGM	Navigation Selector (Co-Pilot)	1	15	0.000057
51DJF	Selector Switch (Pilot)	2	169	0.000642
51DJG	Selector Switch (Co-Pilot)	1	159	0.000604
			360	0.001368

TOTAL FLIGHT HOURS = 263254 HOURS

$MTBF = (\Sigma\lambda)^{-1} = 730.994$

PITCH ATTITUDE GYRO

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
52AAF	Vertical Gyro	1	690	0.002621
			690	0.002621

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 381.534 HOURS

PITCH RATE GYRO

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
52AAC	Gyro - Two Axis Rate	2	171*	0.000650
			171	0.000650

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 1538.462 HOURS

* Gyro Measures both Pitch and Roll Rate so the failures were divided equally between Pitch Rate Gyro and the Roll Rate Gyro.

RADAR INDICATOR

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
72JBO	Indicator Assembly	1	267	0.001014
			267	0.001014

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 493.097 HOURS

NOTE: Two Radar Indicator were used on the Test Aircraft so $\Sigma\lambda = (2)\ (0.001014)$

RADAR RECEIVER TRANSMITTER UNIT

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
72JAO	RT Assembly	1	545	0.002070
72JCO	Antenna	1	16	0.000061
72JDO	Mount	1	0	0.000000
			561	0.002131

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 234.632 HOURS

NOTE: Two Radar Receiver Transmitter Units were used in the Test Aircraft so $\Sigma\lambda = (2)\ (0.002131)$

ROLL RATE GYRO

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
52AAC	Gyro-Two Axis Rate	2	171*	0.000650
				0.000650

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 1538.462 HOURS

* **Gyro measures both Pitch and Roll Rate so the failures were divided equally between the Pitch Rate Gyro and the Roll Rate Gyro**

ROTATE AND GO-AROUND COMPUTER

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
56BJO	Computer Rotation Go-Around	1	464	0.001763
56DJD	Accelerometer - Vertical	1	14	0.000053
56DJE	Accelerometer - Horizontal	1	23	0.000087
14JBF	Angle of Attack Transducer	2	N/A	0.001024*
			501	0.002927

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 341.647 HOURS

* C-141 Failure Rate Data from August 1975 to January 1976
(134 Failures occurred during 130804 Flight Hours)

RUNWAY DISTANCE REMAINING INDICATOR

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
N/A	RDR Indicator	1	N/A	0.005438*
				0.005438

$MTBF = (\Sigma\lambda)^{-1} = 183.9$ HOURS

* **No Fleet Failure Rate Data Available - No failures occurred for 183.9 Test Flight Hours from July 1974 to June 1975 so assumed a maximum of 1 Failure per 183.9 Hours.**

AD-A087 524   DAYTON UNIV OHIO   F/G 1/2

LANDING SYSTEM RELIABILITY AND SAFETY MODEL.(U)

AUG 79 L FUDGE, L GEPHART, G YINGLING   F33615-74-C-3075

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SIMPLIFIED TERMINAL AREA CONTROL COMPUTER

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
N/A	STACC	2	N/A	0.001442*
13ACA	Touchdown Switch	4	132	0.000501
13ACB	Touchdown Relay	10	21	0.000080
13BCA	Switch NLG	1	45	0.000171
13DCA	Skid Detector	8	128	0.000486
13DCB	Control Box, Anti-Skid	1	428	0.001626
14HBN	Touchdown Control Box	1	156	0.000593
56DJB	Transmitter	2	1	0.000004
56DJD	Accelerometer	3	41	0.000156
			952	0.005059

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 197.668 HOURS

* ESTIMATED FAILURE RATE BASED ON SIMILAR EQUIPMENT

TEST PROGRAMMER AND LOGIC COMPUTER

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
56DGA	Program Control Board	1	82	0.000311
56DGB	Indicator Logic Board	1	34	0.000129
56DGC	Monitor Logic Board	1	46	0.000175
56DGD	R/GA Gyro Monitor Board	1	112	0.000425
56DGE	Vertical Gyro Monitor Board	2	105	0.000399
56DGF	Special Circuits Board	2	49	0.000186
56DGG	Left Power Supply Board	1	97	0.000368
56DGH	Right Power Supply Board	1	92	0.000349
56DGJ	Clamp Circuit Board	1	0	0.000000
56DGK	Interrupter Circuit Board	1	8	0.000030
56DGL	Relay Assembly Board	1	4	0.000015
56DJA	Test Panel	1	17	0.000065
			646	0.002452

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 407.830 HOURS

VERTICAL GYRO

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
52AAF	Vertical Gyro	1	690	0.002621
				0.002621

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 381.534 HOURS

YAW DAMPER COMPUTER

WORK UNIT CODE	DESCRIPTION	QTY/Pa	C-141 FLEET FAILURES FROM MAY 1974 to APRIL 1975	FAILURE RATE (λ), FAILURES/HOUR
52EBA	Module Logic	1	128	0.000486
52EBB	Adapter Module	1	70	0.000266
52EBC	Comparator Assembly	1	73	0.000277
52EBD	Signal Chain Comparator Assy.	1	106	0.000403
52EBE	Servo Drive	1	90	0.000342
52EBF	Filter YAW Rate	1	258	0.000980
52EBG	Simulator Module	1	93	0.000353
52EBH	Power Supply	1	48	0.000182
			866	0.003289

TOTAL FLIGHT HOURS = 263254 HOURS

MTBF = $(\Sigma\lambda)^{-1}$ = 304.044 HOURS

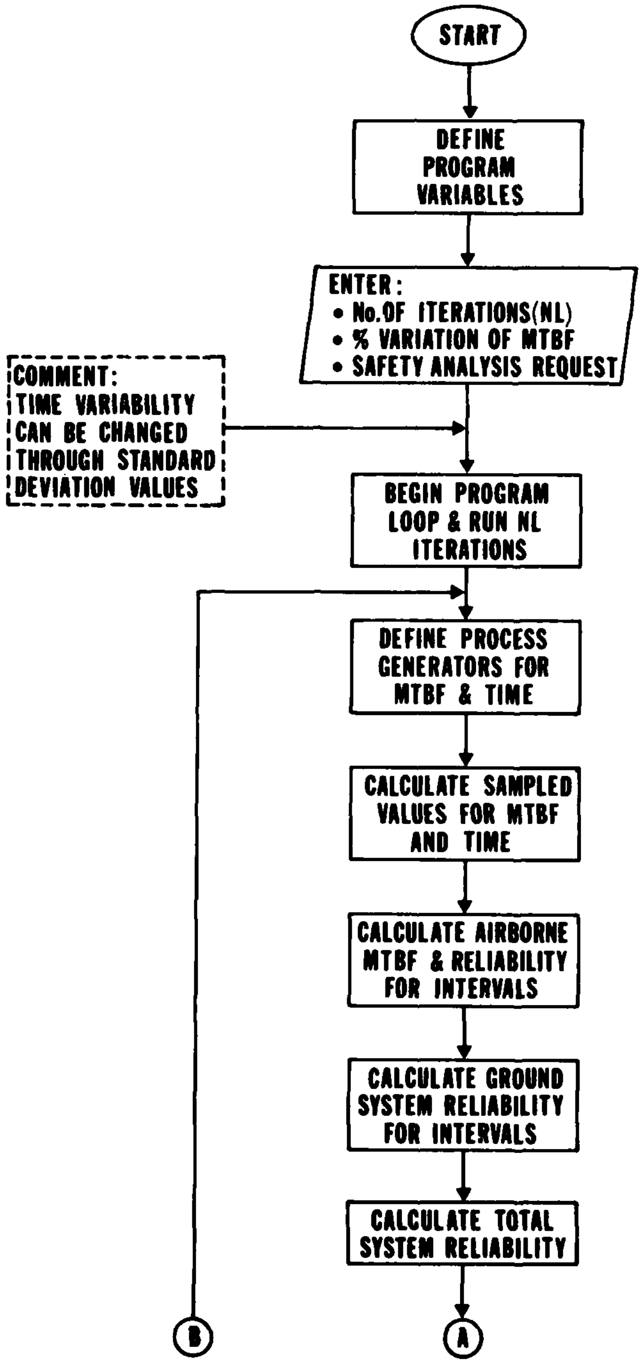
APPENDIX B

COMPUTER PROGRAM INFORMATION

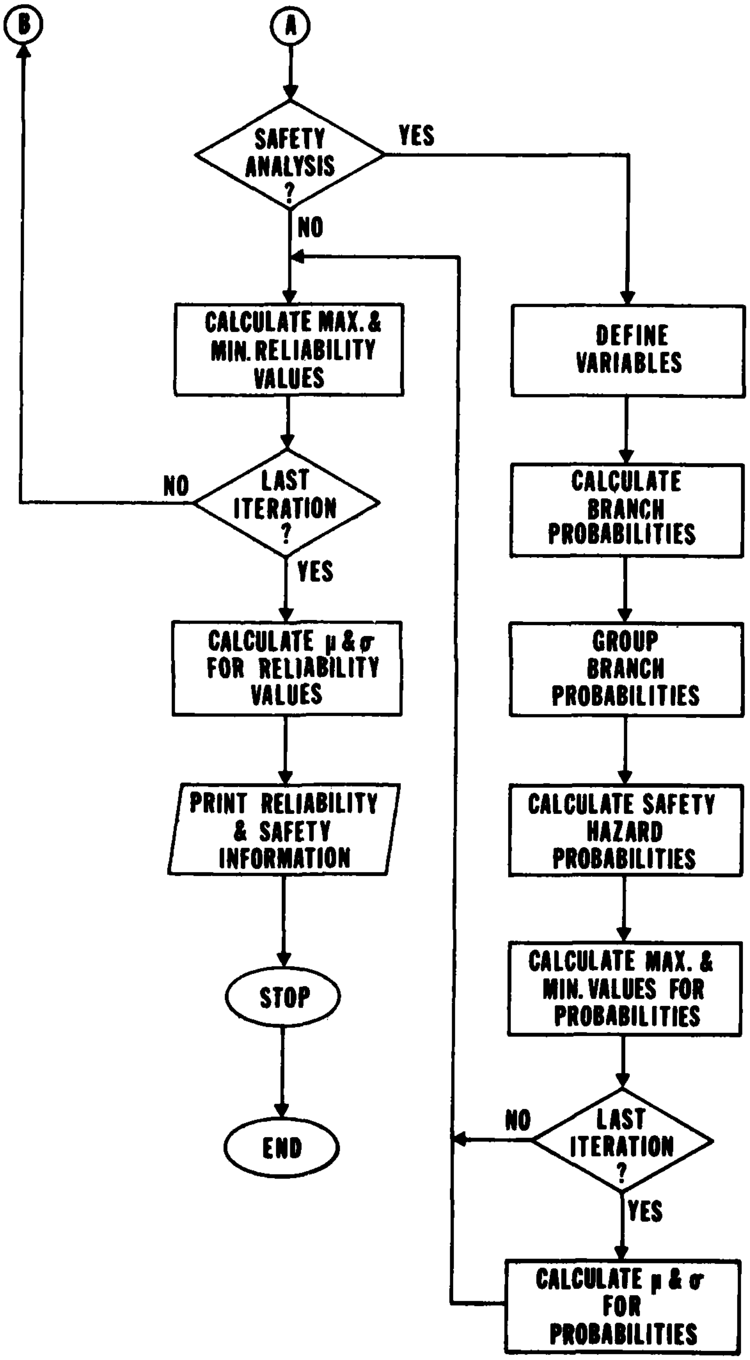
APPENDIX B

The computer programs for this reliability/safety analysis were designed to provide the respective calculations for both system configurations (Category III Adapter and STACC). Each system configuration had a separate computer program which provided the analysis via a Monte Carlo simulation. This simulation technique allowed the respective calculations to reflect the influence of MTBF and operational time variability on the reliability/safety values. Thus, the programs determined not only the nominal probability values but also determined the variability associated with each calculation. A simplified flow chart for the basic computer programs is illustrated in Figures B1 and B2. Descriptions of the basic process generators for the Monte Carlo simulations and computer printouts for both system configurations are included in this appendix.

COMPUTER ANALYSIS FLOW CHART

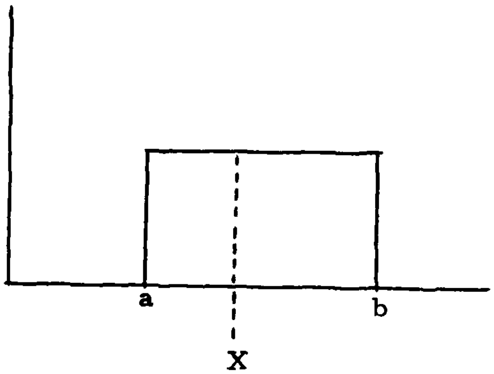


COMPUTER ANALYSIS FLOW CHART (Cont.)



Uniform Process Generator

For a uniformly distributed random variable X



$$f_x(X) = \frac{1}{b-a}, \quad a < X < b$$

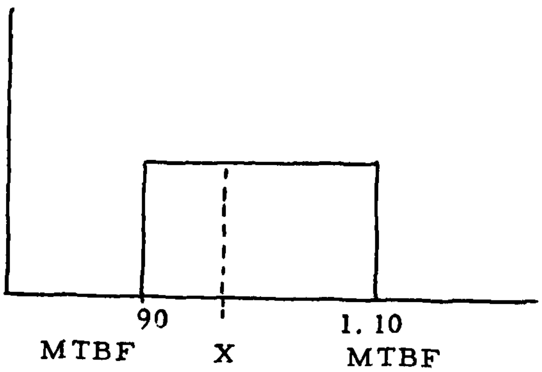
$$r = \int_a^X \frac{dz}{b-a}$$

$$r = \frac{X-a}{b-a}$$

$$\therefore \; X = a + r(b-a)$$

where r is a random number between 0 and 1.

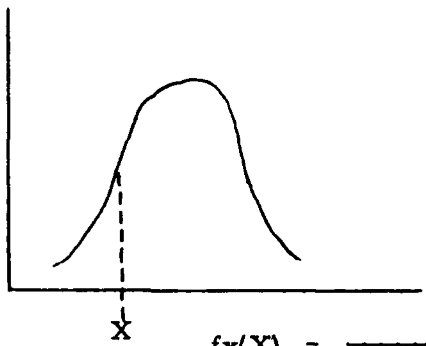
Th individual process generators for equipment MTBF were based on this uniform distribution with a variability of $\pm$ 10 percent from the nominal MTBF values. This is illustrated as follows:



where the sampled values from the distributions can be represented by $X = .90MTBF + (r)\ (.20\ MTBF)$.

Normal Process Generator

For a normally distributed random variable X



where μ = mean

and σ^2 = variance

$$fx(X) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(t-\mu)^2/(2\sigma^2)} dt$$

$$r = \int_{-\infty}^{X} \frac{1}{\sigma\sqrt{2\pi}} e^{-(t-\mu)^2/(2\sigma^2)} dt$$

where r is a random number between 0 and 1. However, this integral cannot be evaluated analytically but can be evaluated with the use of an approximation for the cumulative standard normal distribution (mean 0 and variance 1). The standard normal distribution employs the following transformations:

$$Z = \frac{t-\mu}{\sigma}$$

$$dt = \sigma\, dZ$$

therefore $r = \int_{-\infty}^{\frac{X-\mu}{\sigma}} \frac{1}{2\pi} e^{-Z/2} dZ$

Because of the symmetry of the normal distribution about the mean (r=0.5) and the computational approximation, the variable X can be represented as

$$X = \mu + \frac{r - 0.5}{|r - 0.5|}\, \sigma \left(V - \frac{2.515517 + 0.802853V + 0.010328V^2}{1 + 1.432788V + 0.189269V^2 + 0.001308V^3} \right)$$

where $V = \sqrt{-2 \ln 0.5\ (1 - |1 - 2r|\ )}$

The normal distribution process generators were used to determine the sampled values for the modeled time segments of the landing profile. Values for the Mean (μ) and standard deviation (σ) for each time segment served as inputs to the respective process generators.

Reliability/Safety Analysis Results

(STACC System Configuration)

SAFETY ANALYSIS RESULTS

	SYSTEM CONFIGURATION	
	CATEGORY III ADAPTER	STACC
SAFETY HAZARD (FULLY AUTOMATIC)	$\mu = 199 \times 10^{-7}$* $\sigma = 10 \times 10^{-7}$*	$\mu = 23 \times 10^{-12}$* $\sigma = 2 \times 10^{-12}$*
SAFETY HAZARD (AUTOMATIC/MANUAL ASSIST)	$\mu = 92 \times 10^{-7}$* $\sigma = 6 \times 10^{-7}$*	$\mu = 9 \times 10^{-12}$* $\sigma = 1 \times 10^{-12}$*

* Per Landing

Run # 1

Did Not Vary Either Equipment MTBF
or Segment Time Intervals

XPER=0%.
STD DEV. = 0.

```
                 1.024 CP SECONDS              77500B CM STORAGE US

*EOR
1$AWLS
0NL       = 100,
0XPER     = 0.0,
0ANS      = 1,
0$END

                         RELIABILITY ANALYSIS

          LOC CAPTURE TO ARM G/S

      MEAN TIME =                       210.
      STD. DEV.  OF TIME =              0.
      MTBF =                            16.63860600796584890906642 36
      VARIATION =                       0.
      MEAN OF RELIABILITY =             .99649651475417568445616106 5
      STD. DEV.  OF RELIABILITY =       0.
      MAX VALUE =                       .99649651475417568445616106 6
      MIN VALUE =                       .99649651475417568445616106 6

          ARM G/S TO G/S CAPTURE

      MEAN TIME =                       30.
      STD. DEV.  OF TIME =              0.
      MTBF =                            16.10197335116438119548699 08
      VARIATION =                       0.
      MEAN OF RELIABILITY =             .99948206591400672640857694 4
      STD. DEV.  OF RELIABILITY =       0.
      MAX VALUE =                       .99948206591400672640857694 5
      MIN VALUE =                       .99948206591400672640857694 5

          G/S CAPTURE TO APPROACH ARM

      MEAN TIME =                       30.
      STD. DEV.  OF TIME =              0.
      MTBF =                            15.16249830744916546286334 97
      VARIATION =                       0.
      MEAN OF RELIABILITY =             .99945001634632992574556009 9
      STD. DEV.  OF RELIABILITY =       0.
      MAX VALUE =                       .99945001634632992574556 01
      MIN VALUE =                       .99945001634632992574556 01
```

```
          APPROACH ARM TO LAND ARM (100 FEET)

     MEAN TIME =                     81. 54
     STD. DEV.  OF TIME =            0.
     MTBF =                          11. 831810403275117001155 6572
     VARIATION =                     0.
     MEAN OF RELIABILITY =             99808605333558595790496 5218
     STD. DEV.  OF RELIABILITY = 0:
     MAX VALUE =                     . 99808605333558595790496 5219
     MIN VALUE =                     . 99808605333558595790496 5219




      LAND ARM (100 FT) TO FLARE ENGAGE (45 FT)

     MEAN TIME =                     5. 35
     STD. DEV.  OF TIME =            0.
     MTBF =                          11. 831810403275117001155 6572
     VARIATION =                     0.
     MEAN OF RELIABILITY =            99987430976868340894065 2405
     STD. DEV.  OF RELIABILITY = 0.
     MAX VALUE =                      99987430976868340894065 2406
     MIN VALUE =                      99987430976868340894065 2406




        FLARE ENGAGE (45 FT) TO DECRAB (20 FT)

     MEAN TIME =                     3. 07
     STD. DEV.  OF TIME =            0.
     MTBF =                          12. 119020550940566804625 6485
     VARIATION =                     0.
     MEAN OF RELIABILITY =            9999295810122615929934 4016
     STD. DEV.  OF RELIABILITY = 0.
     MAX VALUE =                      99992958101226159299344 0161
     MIN VALUE =                      99992958101226159299344 0161




          DECRAB (20 FT) TO TOUCHDOWN

     MEAN TIME =                     4. 02
     STD. DEV.  OF TIME =            0.
     MTBF =                          12. 119020550940566804625 6485
     VARIATION =                     0.
     MEAN OF RELIABILITY =           . 99990779112490409256949 1272
     STD. DEV.  OF RELIABILITY = 0.
     MAX VALUE =                     . 99990779112490409256949 1273
     MIN VALUE =                     . 99990779112490409256949 1273




          TOUCHDOWN TO STOP

     MEAN TIME =                     22. 73
     STD. DEV.  OF TIME =            0.
     MTBF =                          14. 3955465794716898297868 169
     VARIATION =                     0.
     MEAN OF RELIABILITY =           . 9995610920998680581480 2197
     STD. DEV.  OF RELIABILITY = 0.
```

```
          TOUCHDOWN TO STOP

     MEAN TIME =                     22.73
     STD. DEV.  OF TIME =            0.
     MTBF =                          14.3955465794716898297868169
     VARIATION =                     0.
     MEAN OF RELIABILITY =           .99956109209986805814802197
     STD. DEV.  OF RELIABILITY =     0.
     MAX VALUE =                     .999561092099868058148021971
     MIN VALUE =                     .999561092099868058148021971




             TOTAL RELIABILITY FROM APPROACH ARM TO STOP

     MEAN OF RELIABILITY =            99736037238578385541797997
     STD. DEV.  OF RELIABILITY =     0.
     MAX VALUE =                     .99736037238578385541797997
     MIN VALUE =                     .99736037238578385541797997




             TOTAL RELIABILITY FOR COMPLETE MODEL

     MEAN OF RELIABILITY =           .992805050867921586088078687
     STD. DEV.  OF RELIABILITY =     9.13345966917193040081249268E-28
     MAX VALUE =                     .992805050867921586088078688
     MIN VALUE =                     .992805050867921586088078688




                        SAFETY ANALYSIS



        SYSTEM OPERATIONAL

     PROBABILITY = .999398725063109384554684044
     STD. DEV.  =     0.
     MAX VALUE =    .999398725063109384554684045
     MIN VALUE =    .999398725063109384554684045



       NON-CRITICAL FAILURE AND SUCCESSFUL R/GA

     PROBABILITY = .000177097416518783158734848692
     STD. DEV,  =     0.
     MAX VALUE =    .000177097416518783158734848692
     MIN VALUE =    .000177097416518783158734848692



   CRITICAL FAILURE TO SINGLE CHANNEL AND SUCCESSFUL R/GA

     PROBABILITY = .00000418858433413708238411910654
     STD. DEV.  =     0.
     MAX VALUE =    .00000418858433413708238411910654
     MIN VALUE =    .00000418858433413708238411910654
```

```
WHEEL SPIN-UP NOT DETECTED AND SUCCESSFUL R/GA

PROBABILITY = 5.02417836143932675562906951E-7
STD. DEV.  =   0.
MAX VALUE =    5.02417836143932675562906951E-7
MIN VALUE =    5.02417836143932675562906951E-7


 NON-CRITICAL FAILURE DURING ROLLOUT

PROBABILITY = .000401738258243065112817239977
STD. DEV.  =   0.
MAX VALUE =    .000401738258243065112817239977
MIN VALUE =    .000401738258243065112817239977


      BACK-UP ROLLOUT MODE

PROBABILITY = .00000440905279122985843392858097
STD. DEV.  =   0.
MAX VALUE =    .00000440905279122985843392858097
MIN VALUE =    .00000440905279122985843392858097


CRITICAL FAILURE TO SINGLE CHANNEL DURING ROLLOUT

PROBABILITY = .0000133131075125501343315572358
STD. DEV.  =   0.
MAX VALUE =    .0000133131075125501343315572358
MIN VALUE =    .0000133131075125501343315572358


LOCALIZER FAILURE AND SUCCESSFUL R/GA

PROBABILITY = 3.57314729416175607915543686E-8
STD. DEV.  =   0.
MAX VALUE =    3.57314729416175607915543687E-8
MIN VALUE =    3.57314729416175607915543687E-8


        SAFETY HAZARD

PROBABILITY = 4.93533930016005914144274766E-11
STD. DEV.  =   0.
MAX VALUE =    4.93533930016005914144274766E-11
MIN VALUE =    4.93533930016005914144274766E-11


ATTENUATED SAFETY HAZARD (NO PILOT VISIBILITY)

PROBABILITY = 2.28697741158848983268402639E-11
STD. DEV.  =   0.
MAX VALUE =    2.28697741158848983268402639E-11
MIN VALUE =    2.28697741158848983268402639E-11
```

```
    ATTENUATED SAFETY HAZARD (NO PILOT VISIBILITY)

      PROBABILITY = 2.28697741158848983268402639E-11
      STD. DEV.  =      0.
      MAX VALUE  =    2.28697741158848983268402639E-11
      MIN VALUE  =    2.28697741158848983268402639E-11



    ATTTENUATED SAFETY HAZARD (LIMITED PILOT VISIBILITY)

      PROBABILITY = 8.69948112223602469043029332E-12
      STD. DEV.  =      0.
      MAX VALUE  =    8.69948112223602469043029332E-12
      MIN VALUE  =    8.69948112223602469043029332E-12
*EOR
1  CSB     NOS/BE L414H ECS    CYBR CMR3 05/30/77
 13.41.48.PATIAEI   FROM     /IA
 13.41.48.IP  00000128 WORDS - FILE INPUT  , DC 00
 13.41.48.PAT(T25,I050,CM100000,STCSB) D760276,BUS
 13.41.48.SINGER,UD,229-4238
 13.41.50.ATTACH(LGO,AWLSSBIN,CY=1)
 13.53.34.MAP(PART)
 13.53.37.LGO,
 13.54.39.     STOP
 13.54.39.      2.451 CP SECONDS EXECUTION TIME
 13.54.39.OP  00001600 WORDS - FILE OUTPUT   DC 40
 13.54.39.MS     3584  WORDS  (     3584 MAX USED)
 13.54.39.SCM 100000  WORDS MAXIMUM
 13.54.39.CPA        3.525 SEC.          1.530 ADJ.
 13.54.39.IO         1.256 SEC.           .628 ADJ.
 13.54.39.CM      123.164 KWS.            .985 ADJ.
 13.54.39.CRUS                           3.144
 13.54.39.COST                 $           18
 13.54.39.PP         4.712 SEC.      DATE 07/20/77
 13.54.39.EJ  END OF JOB, IA  D760276.
```

Run # 2

Only Varied Equipment MTBF

```
ONL      = 100,
OXPER    = .1E+00,
OANS     = 1,
O$END
```

AWLS3
XPER = 10%
STD DEV. = 0.

RELIABILITY ANALYSIS

LOC CAPTURE TO ARM G/S

```
MEAN TIME =                   210.
STD. DEV.  OF TIME =          0.
MTBF =                        15.5627623406178475965176369
VARIATION =                   .1
MEAN OF RELIABILITY =         .996478421452194926970490519
STD. DEV.  OF RELIABILITY =   .0000610778416965016436464592313
MAX VALUE =                   .996674327260553816292498876
MIN VALUE =                   .996255143360481563230251245
```

ARM G/S TO G/S CAPTURE

```
MEAN TIME =                   30.
STD. DEV.  OF TIME =          0.
MTBF =                        15.11222965657696955989186
VARIATION =                   .1
MEAN OF RELIABILITY =         .999479498920957791552271811
STD. DEV.  OF RELIABILITY =   .00000884243447765012650059173113
MAX VALUE =                   .99950896882347207308557752
MIN VALUE =                   .999448205083568751601537483
```

G/S CAPTURE TO APPROACH ARM

```
MEAN TIME =                   30.
STD. DEV.  OF TIME =          0.
MTBF =                        14.3440549608996800678151481
VARIATION =                   .1
MEAN OF RELIABILITY =         .999447438901833410938287291
STD. DEV.  OF RELIABILITY =   .00000875223069871343394466683671
MAX VALUE =                   .999477421474920771691780689
MIN VALUE =                   .999418690806811322048072891
```

APPROACH ARM TO LAND ARM (100 FEET)

```
MEAN TIME =                   81.54
STD. DEV.  OF TIME =          0.
MTBF =                        11.2833913689005116325204183
VARIATION =                   .1
MEAN OF RELIABILITY =         .998079400291759936896328902
STD. DEV.  OF RELIABILITY =   .0000262004673455933736972541584
MAX VALUE =                   [illegible]
```

```
      LAND ARM (100 FT) TO FLARE ENGAGE (45 FT)

     MEAN TIME =                    5. 35
     STD. DEV.  OF TIME =           0.
     MTBF =                         11. 28339136890051163252041 83
     VARIATION =                    . 1
     MEAN OF RELIABILITY =          . 99987387242333489425069386 8
     STD. DEV.  OF RELIABILITY = . 000001722137111214002329703480 99
     MAX VALUE =                    . 99987890160693350032273162 2
     MIN VALUE =                    . 99986820857000771516044928 9




        FLARE ENGAGE (45 FT) TO DECRAB (20.FT)

     MEAN TIME =                    3. 07
     STD. DEV.  OF TIME =           0.
     MTBF =                         11. 53266738255820275826111 49
     VARIATION =                    . 1
     MEAN OF RELIABILITY =          . 99992932737378637452908736 9
     STD. DEV.  OF RELIABILITY = 9. 81291744992160219657726629E-7
     MAX VALUE =                    . 99993216173009561571495439 3
     MIN VALUE =                    . 99992600524829199568365761 7




           DECRAB (20 FT) TO TOUCHDOWN

     MEAN TIME =                    4. 02
     STD. DEV.  OF TIME =           0.
     MTBF =                         11. 53266738255820275826111 49
     VARIATION =                    . 1
     MEAN OF RELIABILITY =          . 99990745900659649027990659 5
     STD. DEV.  OF RELIABILITY = . 000001284920861686370858527497 38
     MAX VALUE =                    . 99991117036390819501547241 4
     MIN VALUE =                    . 99990310895879920647165073 2




           TOUCHDOWN TO STOP

     MEAN TIME =                    22. 73
     STD. DEV.  OF TIME =           0.
     MTBF =                         13. 65137131694590413546018 65
     VARIATION =                    . 1
     MEAN OF RELIABILITY =          . 99955921497548541646867383 6
     STD. DEV.  OF RELIABILITY = . 000007031635218419279420172396 51
     MAX VALUE =                    . 99957862707332415551407453 2
     MIN VALUE =                    . 99953720558006143284252753 6




               TOTAL RELIABILITY FROM APPROACH ARM TO STOP

     MEAN OF RELIABILITY =          . 99735088313472330017216059 5
     STD. DEV.  OF RELIABILITY = . 000052979727582034216259357814 8
     MAX VALUE =                    . 99745799573604452144836218 3
     MIN VALUE =                    . 9972294684701706856091619[illegible]
```

TOTAL RELIABILITY FOR COMPLETE MODEL

```
MEAN OF RELIABILITY =          .99277242518937133877939881 8
STD. DEV.  OF RELIABILITY = .000162815844103776118325823798
MAX VALUE =                    .99313336123354051522227237 4
MIN VALUE =                    .99236957249819356328134994 4
```

SAFETY ANALYSIS

SYSTEM OPERATIONAL

```
PROBABILITY = .999396263273854325174451 82
STD DEV.  =    .0000092529010994971807758308011 4
MAX VALUE =    .999422013039362756565141 66
MIN VALUE =    .9993665820922909157257705 75
```

NON-CRITICAL FAILURE AND SUCCESSFUL R/GA

```
PROBABILITY = .00017775311200108151117685369 2
STD. DEV.  =   .0000026480091779132672811401943 4
MAX VALUE =    .00018651353075795860539409525 4
MIN VALUE =    .00017018721156458488363455328 4
```

CRITICAL FAILURE TO SINGLE CHANNEL 'AND SUCCESSFUL R/GA

```
PROBABILITY = .0000041993923396904062461182313 4
STD. DEV.  =   1.8090514301133346800244431 1E-7
MAX VALUE =    .0000046449623959422811481291691 3
MIN VALUE =    .0000038094856343672198790251505 3
```

WHEEL SPIN-UP NOT DETECTED AND SUCCESSFUL R/GA

```
PROBABILITY = 5.0396180020109211048286841 3E-7
STD. DEV.  =   2.0575693513299410391429708 6E-8
MAX VALUE =    5.5724425357665849752520255 2E-7
MIN VALUE =    4.5763805439905509388671485 3E-7
```

NON-CRITICAL FAILURE DURING ROLLOUT

```
PROBABILITY = .00040354622152691100864164222 4
STD DEV.  =    .0000071690329255282200184911072 1
MAX VALUE =    .00042643554910554400137556802 2
MIN VALUE =    .00038447392093843752858336229 4
```

BACK-UP ROLLOUT MODE

```
           BACK-UP ROLLOUT MODE

     PROBABILITY = .00000440581534707980166974649884
     STD. DEV.  =    1.6552582105663236026787653 7E-7
     MAX VALUE =   .00000486019271104528537682430142
     MIN VALUE =   .00000403372081182539560937225682



     CRITICAL FAILURE TO SINGLE CHANNEL DURING ROLLOUT

     PROBABILITY = .0000134143121818500122269768641
     STD. DEV.  =    5.390583696349779159526104 01E-7
     MAX VALUE =   .0000147697701668812553246503019
     MIN VALUE =   .0000121417860553148827362753823



    LOCALIZER FAILURE AND SUCCESSFUL R/GA

     PROBABILITY = 3.578256269209723004957708 17E-8
     STD. DEV.  =    1.1187527212544111251246146 6E-9
     MAX VALUE =   3.900341453445239573279027 26E-8
     MIN VALUE =   3.324800756869141390176580 46E-8



             SAFETY HAZARD

     PROBABILITY = 5.020614802355999770840133 98E-11
     STD. DEV.  =    3.5921121127353400149257544 1E-12
     MAX VALUE =   5.956539468265021085182745 31E-11
     MIN VALUE =   4.136737575861270200427499 52E-11



   ATTENUATED SAFETY HAZARD (NO PILOT VISIBILITY)

     PROBABILITY = 2.323893949652361361896782 45E-11
     STD. DEV.  =    1.4287903303868281914972912 9E-12
     MAX VALUE =   2.737174300968929822108347 99E-11
     MIN VALUE =   1.917716192687264570031310 95E-11



   ATTTENUATED SAFETY HAZARD (LIMITED PILOT VISIBILITY)

     PROBABILITY = 8.809897105295254427440501 09E-12
     STD. DEV.  =    4.6457920411554286716855468 6E-13
     MAX VALUE =   1.051039775839731391729774 11E-11
     MIN VALUE =   7.265601722003676590295037 39E-12
+EOR
1  CSB     NOS/BE L414H ECS    CYBR CMR3 05/30/77
 10.57.05.PATIA6Y  FROM     /IA
 10.57.05.IP  00000256 WORDS - FILE INPUT  , DC 00
 10.57.05.PAT(T25,I050,CM100000,STCSB) D760276,BUS
 10.57.05.SINGER,UD,229-4236
 10.57.07.ATTACH(LGO,AWLSSBIN,CY=1)
 10.57.07.MAP(PART)
 10.57.07.LGO.
 10.57.18.       STOP
 10.57.18.        2.422 CP SECONDS EXECUTION TIME
 10.57.18.OP  00001664 WORDS - FILE OUTPUT , DC.40
 10.57.18.MS     3584  WORDS  (     3584 MAX USED)
```

Run # 3

Only Varied Segment Time Intervals

RELIABILITY ANALYSIS

XPER = 0%
STD DEV. = vary

```
     LOC CAPTURE TO ARM G/S

MEAN TIME =                 210.
STD. DEV.  OF TIME =        0.
MTBF =                      16. 638606007965848909066423б
VARIATION =                 0.
MEAN OF RELIABILITY =       . 9964965147541756844561610б5
STD. DEV.  OF RELIABILITY = 0.
MAX VALUE =                 . 996496514754175684456161066
MIN VALUE =                 . 996496514754175684456161066


     ARM G/S TO G/S CAPTURE

MEAN TIME =                 30.
STD. DEV.  OF TIME =        0.
MTBF =                      16. 101973351164381195486990б
VARIATION =                 0.
MEAN OF RELIABILITY =        999482065914006726408576944
STD. DEV.  OF RELIABILITY = 0.
MAX VALUE =                 . 999482065914006726408576945
MIN VALUE =                 . 999482065914006726408576945


     G/S CAPTURE TO APPROACH ARM

MEAN TIME =                 30.
STD. DEV.  OF TIME =        0.
MTBF =                      15. 1624983074491654628633497
VARIATION =                 0.
MEAN OF RELIABILITY =        999450016346329925745560099
STD. DEV.  OF RELIABILITY = 0.
MAX VALUE =                 . 9994500163463299257455601
MIN VALUE =                 . 9994500163463299257455601


     APPROACH ARM TO LAND ARM (100 FEET)

MEAN TIME =                 81. 54
STD. DEV.  OF TIME =        1. 95
MTBF =                      11. 8318104032751170011556572
VARIATION =                 0.
MEAN OF RELIABILITY =       . 9980818852952497543943533438
STD. DEV.  OF RELIABILITY = . 00002798712493529882871412666639
MAX VALUE =                 . 998175945192777186241345б3
MIN VALUE =                 . 9979813235033132275477б0547


     LAND ARM (100 FT) TO FLARE ENGAGE (45 FT)
```

LAND ARM (100 FT) TO FLARE ENGAGE (45 FT)

```
MEAN TIME =                    5.35
STD. DEV.  OF TIME =            42
MTBF =                         11.83181040327511700011556572
VARIATION =                    0.
MEAN OF RELIABILITY =          .99987373027542382100898171 5
STD. DEV.  OF RELIABILITY =    .00000657809497764322164173335053
MAX VALUE =                    .9998958815400894499177428 86
MIN VALUE =                    .9998545198643131663537713 24
```

FLARE ENGAGE (45 FT) TO DECRAB (20 FT)

```
MEAN TIME =                    3.07
STD. DEV.  OF TIME =           .33
MTBF =                         12.11902055094056680462564 85
VARIATION =                    0.
MEAN OF RELIABILITY =          .99992955590321403445807001 1
STD. DEV.  OF RELIABILITY =    .0000045050677951603490710024 4435
MAX VALUE =                    .99994578549819666827971498 1
MIN VALUE =                    .99991293662817747413268057 9
```

DECRAB (20 FT) TO TOUCHDOWN

```
MEAN TIME =                    4.02
STD. DEV.  OF TIME =           .33
MTBF =                         12.11902055094056680462564 85
VARIATION =                    0.
MEAN OF RELIABILITY =          .99990753671234672045388492 1
STD. DEV.  OF RELIABILITY =    .00000410819621584265623913395826
MAX VALUE =                    .99991932597962661507630908 4
MIN VALUE =                    .99989224541876612460962481 7
```

TOUCHDOWN TO STOP

```
MEAN TIME =                    22.73
STD. DEV.  OF TIME =           .53
MTBF =                         14.39554657947168982978681 69
VARIATION =                    0.
MEAN OF RELIABILITY =          .99956223775122908354953094 7
STD. DEV.  OF RELIABILITY =    .00000581500136618368307838058308
MAX VALUE =                    .99957931396121507539409603 8
MIN VALUE =                    .99953787241811343516066756 4
```

TOTAL RELIABILITY FROM APPROACH ARM TO STOP

```
MEAN OF RELIABILITY =          .99735649367412953796454437 6
STD. DEV.  OF RELIABILITY =    .000043311231111392863158817 7653
MAX VALUE =                    .99745955529780077365780882 5
MIN VALUE =                    .99724900912841418175158249 4
```

```
              TOTAL RELIABILITY FOR COMPLETE MODEL

     MEAN OF RELIABILITY =        .99280118987180836059722401
     STD. DEV.  OF RELIABILITY = .00004311341236050858559577774751
     MAX VALUE =                  .99290378077411851758235709
     MIN VALUE =                  .992694196248609570365249672




                          SAFETY ANALYSIS



         SYSTEM OPERATIONAL

     PROBABILITY = .999399590857948354081746889
     STD. DEV.  =   .00000819267269944700299533706997
     MAX VALUE =    .999424628311097787633861972
     MIN VALUE =    .999364739362442929926823562



        NON-CRITICAL FAILURE AND SUCCESSFUL R/GA

     PROBABILITY = .000177370395922341387489218424
     STD. DEV.  =   .00000605036960105667608214060276
     MAX VALUE =    .00020815573701626639637704216
     MIN VALUE =    .000161079029948026002369505641



    CRITICAL FAILURE TO SINGLE CHANNEL AND SUCCESSFUL R/GA

     PROBABILITY = .00000419489480875390671682375476
     STD. DEV.  =   1.39846225970018635038940959E-7
     MAX VALUE =    .00000490645960255154527269644996
     MIN VALUE =    .00000381834193367162929534332906



     WHEEL SPIN-UP NOT DETECTED AND SUCCESSFUL R/GA

     PROBABILITY = 5.02417695793324884777606484E-7
     STD. DEV.  =   2.75573103311034807819258381E-12
     MAX VALUE =    5.02426073006941442500794247E-7
     MIN VALUE =    5.02401864237433678810229176E-7



       NON-CRITICAL FAILURE DURING ROLLOUT

     PROBABILITY = .000400641229813917295722069718
     STD. DEV.  =   .00000583313254764195533901803631
     MAX VALUE =    .000423971587785637459064039671
     MIN VALUE =    .000384287757414238326962952253



           BACK-UP ROLLOUT MODE

     PROBABILITY =  00000439729958162000474237389579
     STD. DEV.  =   6.31533813055210279401519803E-8
```

```
      PROBABILITY = .00000439729958162000474237389579
      STD. DEV.  =    6.3153381305521027940151980 3E-8
      MAX VALUE =    .000004645755647117767384833 97374
      MIN VALUE =    .00000421844868726770889822829112


      CRITICAL ,FAILURE TO SINGLE CHANNEL DURING ROLLOUT

      PROBABILITY = .0000132767476205928650511442638
      STD. DEV.  =    1.9333910516942767265710 2022E-7
      MAX VALUE =    .0000140500364874645044639258 94
      MIN VALUE =    .0000127347171269591698836062473


     LOCALIZER FAILURE AND SUCCESSFUL R/GA

      PROBABILITY = 3.57442263918145417953250397E-8
      STD. DEV.  =    2.57288373422436591063380895E-9
      MAX VALUE =    4.41774333000440023092185144E-8
      MIN VALUE =    2.75088768349723598428603043E-8


              SAFETY HAZARD

      PROBABILITY = 4.91512126602665516230429207E-11
      STD. DEV.  =    1.34156943516885299743324883E-12
      MAX VALUE =    5.42418621266350633231748237E-11
      MIN VALUE =    4.53918120697171214739004621E-11


    ATTENUATED SAFETY HAZARD (NO PILOT VISIBILITY)

      PROBABILITY = 2.27621172337218714837683456E-11
      STD. DEV.  =    8.51322188733347504377530892E-13
      MAX VALUE =    2.58424576706730372241530572E-11
      MIN VALUE =    2.03676237465327778644253642E-11


    ATTTENUATED SAFETY HAZARD (LIMITED PILOT VISIBILITY)

      PROBABILITY = 8.67119539094073542047424197E-12
      STD. DEV.  =    4.61128820185638625907389339E-13
      MAX VALUE =    1.02761497722397776479637723E-11
      MIN VALUE =    7.42291266014296861480799325E-12
*EOR
1  CSB     NOS/BE L414H ECS   CYBR CMR3 05/30/77
 14 33.10.FATIAGL  FROM    /IA
 14.33.10.IP  00000256 WORDS - FILE INPUT  , DC 00
 14 33.10.FAT(T25,I050,CM100000,STCSB) D760276,BUS
 14 33 10.SINGER,UD,229-4238
 14 33.14.ATTACH(LGO,AWL33BIN,CY=1)
 15.17.35.MAP(PART)
 15 17 35.LGO.
 15 18.18.     STOP
 15 18 18.      2.423 CP SECONDS EXECUTION TIME
 15 18.18.OP  00001664 WORDS - FILE OUTPUT , DC 40
 15 18 19.MS    3584  WORDS  (    3584 MAX USED)
 15 18 19 SCM 100000  WORDS MAXIMUM
```

Run # 4

Varied Both Equipment MTBF
and Segment Time Intervals

AWLS3

XPER = 10%

STD.DEV. = vary

```
IOR
1$AWLS
0NL         = 100,
0XPER       = .1E+00,
0ANS        = 1,
0$END
```

RELIABILITY ANALYSIS

LOC CAPTURE TO ARM G/S

```
MEAN TIME =                     210.
STD. DEV.  OF TIME =            0.
MTBF =                          15.5627623406178475965176369
VARIATION =                     .1
MEAN OF RELIABILITY =           .996478421452194926970490519
STD. DEV.  OF RELIABILITY =     .0000610778416965016436464592313
MAX VALUE =                     .996674327260553816292498876
MIN VALUE =                     .996255143360481563230251245
```

ARM G/S TO G/S CAPTURE

```
MEAN TIME =                     30.
STD. DEV.  OF TIME =            0.
MTBF =                          15.11222965657696955989186
VARIATION =                     .1
MEAN OF RELIABILITY =           .999479498920957791552271811
STD. DEV.  OF RELIABILITY =     .00000884243447765012650059173113
MAX VALUE =                     .999508968823472073085557752
MIN VALUE =                     .999448205083568751601537483
```

G/S CAPTURE TO APPROACH ARM

```
MEAN TIME =                     30.
STD. DEV.  OF TIME =            0.
MTBF =                          14.3440549608996800678151481
VARIATION =                     .1
MEAN OF RELIABILITY =           .999447438901833410938287291
STD. DEV  OF RELIABILITY =      .00000875223069871343394466683671
MAX VALUE =                     .999477421474920771691780689
MIN VALUE =                     .999418690806811322048072891
```

APPROACH ARM TO LAND ARM (100 FEET)

```
MEAN TIME =                      81.54
STD. DEV.  OF TIME =             1.95
MTBF =                           11.28339136890051163252O4183
VARIATION =                      .1
MEAN OF RELIABILITY =            .998075136531058483272648362
STD. DEV.  OF RELIABILITY =      .0000411612447796890451613976049
MAX VALUE =                      .998207026286445345882872238
MIN VALUE =                      .997927956717327331216968208


 LAND ARM (100 FT) TO FLARE ENGAGE (45 FT)

MEAN TIME =                      5.35
STD. DEV.  OF TIME =              42
MTBF =                           11.283391368900511632520418З
VARIATION =                      .1
MEAN OF RELIABILITY =            .999873306630743929251607118
STD. DEV.  OF RELIABILITY =      .0000067152859041516443528939876５
MAX VALUE =                      .999896654125706098503884997
MIN VALUE =                      .999853337492958250144825517


   FLARE ENGAGE (45 FT) TO DECRAB (20 FT)

MEAN TIME =                      3.07
STD. DEV.  OF TIME =             .33
MTBF =                           11.532667382558202758261114９
VARIATION =                      .1
MEAN OF RELIABILITY =            .999929287774526408663383665
STD. DEV.  OF RELIABILITY =      .0000048003883712724239519537173７
MAX VALUE =                      .999944387749519165267621064
MIN VALUE =                      .999912631276198295627428615


     DECRAB (20 FT) TO TOUCHDOWN

MEAN TIME =                      4.02
STD. DEV.  OF TIME =             .33
MTBF =                           11.532667382558202758261114９
VARIATION =                      .1
MEAN OF RELIABILITY =            .999907205563827281417056708
STD. DEV.  OF RELIABILITY =      .0000041938890221030160526256856
MAX VALUE =                      .999920485801657260664137117
MIN VALUE =                      .999890413904913365060483313


     TOUCHDOWN TO STOP

MEAN TIME =                      22.73
STD. DEV.  OF TIME =             .53
MTBF =                           13.651371316945904135460186５
VARIATION =                      .1
MEAN OF RELIABILITY =            .999560374547538541025679584
STD. DEV.  OF RELIABILITY =      .0000086813463926560001598917858４
MAX VALUE =                      [illegible]
```

TOTAL RELIABILITY FROM AFFROACH ARM TO STOP

```
MEAN OF RELIABILITY =           .9973468710997744775936804433
STD. DEV.  OF RELIABILITY =     .0000711747131688185422785817012
MAX VALUE =                     .997505555616564602758040872
MIN VALUE =                     .997173039901273023236880494
```

TOTAL RELIABILITY FOR COMPLETE MODEL

```
MEAN OF RELIABILITY =           .992768483196543100317301448
STD. DEV.  OF RELIABILITY =     .000169992045813652759638847632
MAX VALUE =                     .993157174860233009007154266
MIN VALUE =                     .992330762900879792428881654
```

SAFETY ANALYSIS

SYSTEM OPERATIQNAL

```
PROBABILITY = .9993971294834436444074419844
STD. DEV.  =  .000012759097059438083033602574
MAX VALUE =   .999438307011958623061753246
MIN VALUE =   .99935487282917363355318202
```

NON-CRITICAL FAILURE AND SUCCESSFUL R/GA

```
PROBABILITY = .000178039512342202201833332396
STD. DEV.  =  .00000661381389984751877520580737
MAX VALUE =   .000210150279430771889580749722
MIN VALUE =   .000156755914099536107026967988
```

CRITICAL FAILURE TO SINGLE CHANNEL AND SUCCESSFUL R/GA

```
PROBABILITY =  00000420580171313983787369107381
STD. DEV.  =   2.30726470401795386047040403E-7
MAX VALUE =    .000004885987696583109183026246
MIN VALUE =    .00000362709896535300610517082276
```

WHEEL SPIN-UP NOT DETECTED AND SUCCESSFUL R/GA

```
PROBABILITY = 5.03961633146150936903127949E-7

STD. DEV.  =   2.05752184845882615053635557E-8
MAX VALUE =    5.57250908494057709417395163E-7
MIN VALUE =    4.57636421843280959101563904E-7
```

```
      PROBABILITY = .00040248302062783289955667l273
      STD. DEV.   =   .00000919715014006288352692713866
      MAX VALUE =     .000436081240626628488008504805
      MIN VALUE =     .00037329263106370459427006855


         BACK-UP ROLLOUT MODE

      PROBABILITY = .00000439341746497146130365324996
      STD. DEV.   =   1.64624720861172233085458211E-7
      MAX VALUE =     .00000485517218210574658547033374
      MIN VALUE =     .00000397095126335711496475678089


      CRITICAL FAILURE TO SINGLE CHANNEL DURING ROLLOUT

      PROBABILITY = .0000133791301122276651866038988
      STD. DEV.   =   5.81052656756328295260765894E-7
      MAX VALUE =     .0000149495829991964320177624132
      MIN VALUE =     .0000119581376079850369757930882


     LOCALIZER FAILURE AND SUCCESSFUL R/GA

      PROBABILITY = 3.57822721877802641257182591E-8
      STD. DEV.   =   2.66562126085419307273057795E-9
      MAX VALUE =     4.66870715206867296390803925E-8
      MIN VALUE =     2.67868862607366090325299207E-8


            SAFETY HAZARD

      PROBABILITY = 5.00194336140559899470724014E-11
      STD. DEV.   =   3.85365314247369441540430333E-12
      MAX VALUE =     6.05868291251784786362268266E-11
      MIN VALUE =     4.00602364661616738471813125E-11


    ATTENUATED SAFETY HAZARD (NO PILOT VISIBILITY)

      PROBABILITY = 2.31409224690063050580642635E-11
      STD. DEV.   =   1.64660746537452689360356998E-12
      MAX VALUE =     2.80542492381032662302985417E-11
      MIN VALUE =     1.83888858280581404789470322E-11


    ATTTENUATED SAFETY HAZARD (LIMITED PILOT VISIBILITY)

      PROBABILITY = 8.78635935899647011918071715E-12
      STD. DEV.   =   5.88578616514211944847734868E-13
      MAX VALUE =     1.07336831659075259519243547E-11
      MIN VALUE =     6.83901195206099879749643317E-12
--EOR
1  CSB     NOS/BE L414H ECS   CYBR CMR3 R.D 14.18
 16.02.27.FATIAJO  FROM    /IA
 16.02.27.IP  00000256 WORDS - FILE INPUT  , DC 00
```

Program Listing for Reliability/Safety Analysis
(Category III Adapter System Configuration)

AWLS 2

7-20-77

AWLS2

XPER = 0%

σ = vary

```
TACJH, DECK

 I8
/
CYCLE NO.  = 001
DECK, 8

A


00=PAT(T25, 1050, CM100000, STCSB) D760276, BUSSINGER, UD, 229-4238
10=ATTACH(LGO, AWLS2BIN, CY=1)
20=MAP(PART)
30=LGO.
40=*EOR
50= $AWLS NL=100, XPER=0.., ANS=1$
TCH, DECK, INPUT, HERE

LES.

CAL FILES--
_S2       CARDS      *DECK       $INPUT      $OUTPUT
          AWLS3      *A3         *LGO         DUM1
MOTE INPUT FILES--
TIAFC
MOTE OUTPUT FILES--
TIAEI
```

Listing of Deck

XPER=0%

LISTING OF AWLS2

XPER=0%

σ = vary

```
      PROGRAM AWLS2 (INPUT,OUTPUT)
      DOUBLE PRECISION NUMAX(8),NUMIN(8),MAXRTA,MAXRTT,MINRTA,MIN

      DOUBLE PRECISION DIFRTM(10),DIF(8),SUMDIF(8),RTADIF,RTTDIF,

      DOUBLE PRECISION RTTSD,DEV(8),DEVRTA,DEVRTT,EL1A,EL1B,EG1,E

      DOUBLE PRECISION EXPL1,EXPL2,EL1,EL2,EL3,EL4,EL5,EL6,EL7,MT

      DOUBLE PRECISION TIME(9),RT(8,100),PMEAN(11)
      DOUBLE PRECISION PDEV(11),PMAX(11),PMIN(11),SRT(8),MEAN(8)
      DOUBLE PRECISION RTT(100),RTAA(100),XMTBF(8),SRTT,SRTAA,VIN

      DOUBLE PRECISION TOP,BOTTOM,VTERM,ABSRN,SUM20A,SUM20B,SUM20

      DOUBLE PRECISION SUM21,SUM22,SUM23,SUM24,SUM25,SUM26,SUM27,

      DOUBLE PRECISION SUM28,RTAAMN,RTTMN,RLOC(8),RGS(8),RGRND(8)

      DOUBLE PRECISION RT7N
      REAL XMEAN(9),STDDEV(9),INS,MCC,NAVREC,NAVSEL,EQUIP(55)
      INTEGER ANS
      COMMON MTBF,EL1,EL2,EL3,EL4,EL5,EL6,EL7,TIME,SUM26,SUM27,SU

      COMMON PMEAN,PDEV,PMAX,PMIN,N,NLOOP,RT6N,RT7N
      NAMELIST/AWLS/NL,XPER,ANS
      DATA NL,XPER,ANS/100,0.1/
      NLOOP=NL
      CALL RANSET(.05)
      READ AWLS
      PRINT AWLS
      DO 60 I=1,8
      SRT(I)=0.
   60 SUMDIF(I)=0.
      SRTAA=0.
      SRTT=0.
      RTASD=0.
      RTTSD=0.
      ADI=103.778
      EQUIP(1)=ADI
      CONTP=631.305
      EQUIP(2)=CONTP
      COUP=165.180
      EQUIP(3)=COUP
      AISERV=2732.240
```

```
80=        ELSERV=7936.508
90=        EQUIP(5)=ELSERV
00=        RUSERV=425.894
10=        EQUIP(6)=RUSERV
20=        AICOMP=360.620
30=        EQUIP(7)=AICOMP
40=        ATC=716.332
50=        EQUIP(8)=ATC
60=        CADC=41.571
70=        EQUIP(9)=CADC
80=        CATIII=112.428
90=        EQUIP(10)=CATIII
00=        ELCOMP=274.650
10=        EQUIP(11)=ELCOMP
20=        FDCOMP=983.284
30=        EQUIP(12)=FDCOMP
40=        FLCOMP=641.849
50=        EQUIP(13)=FLCOMP
60=        GSREC=499.251
70=        EQUIP(14)=GSREC
80=        HSI=343.643
90=        EQUIP(15)=HSI
00=        INS=1033.058
10=        EQUIP(16)=INS
20=        MCC=626.566
30=        EQUIP(17)=MCC
40=        NAVREC=1474.926
50=        EQUIP(18)=NAVREC
60=        NAVSEL=730.994
70=        EQUIP(19)=NAVSEL
80=        PAGYRO=381.534
90=        EQUIP(20)=PAGYRO
00=        PRGYRO=1538.462
10=        EQUIP(21)=PRGYRO
20=        RADIND=493.097
30=        EQUIP(22)=RADIND
40=        RADRT=234.632
50=        EQUIP(23)=RADRT
60=        RRGYRO=1538.462
70=        EQUIP(24)=RRGYRO
80=        RGACOM=341.647
90=        EQUIP(25)=RGACOM
00=        RDR=183.9
10=        EQUIP(26)=RDR
20=        TPLC=407.830
30=        EQUIP(27)=TPLC
40=        VGYRO=381.534
50=        EQUIP(28)=VGYRO
60=        YDCOMP=304.044
70=        EQUIP(29)=YDCOMP
80=        EQUIP(30)=1072.961
90=        EQUIP(31)=552.792
00=        EQUIP(32)=2066.116
10=        EQUIP(33)=127.405
20=        EQUIP(34)=1474.926
30=        EQUIP(35)=2617.801
40=        EQUIP(36)=183.9
50=        EQUIP(37)=10000.
60=        EQUIP(38)=10000.
70=        EQUIP(39)=10000000.
80=        EQUIP(40)=142857.143
90=        EQUIP(41)=10000000.
00=        EQUIP(42)=200000.
10=        EQUIP(43)=500000
```

```
      EQUIP(46)=10000000.
      EQUIP(47)=1000000.
      EQUIP(48)=10000000.
      EQUIP(49)=166666.667
      EQUIP(50)=11671.335
      EQUIP(51)=49504.951
      EQUIP(52)=46685.341
      EQUIP(53)=12376.238
      EQUIP(54)=10000.
      EQUIP(55)=1250000.
      XMEAN(1)=210.
      XMEAN(2)=30.
      XMEAN(3)=30.
      XMEAN(4)=81.54
      XMEAN(5)=5.35
      XMEAN(6)=3.07
      XMEAN(7)=4.02
      XMEAN(8)=22.73
      XMEAN(9)=3.
      STDDEV(1)=0.
      STDDEV(2)=0.
      STDDEV(3)=0.
      STDDEV(4)=1.95
      STDDEV(5)=.42
      STDDEV(6)=.33
      STDDEV(7)=.33
      STDDEV(8)=.53
      STDDEV(9)=0.
      DO 40 N=1,NLOOP
      DO 10 I=1,55
      RN=RANF(DUMMY)
      MTBF(I)=((1.-XPER)*(EQUIP(I)))+((RN)*(2.*XPER)*(EQUIP(I)))
   10 CONTINUE
      DO 30 M=1,9
      RN=RANF(DUMMY)
      VINSID=(-2.)*ALOG(0.5)*(1.-ABS(1.-(2.*RN)))
      V=DSQRT(VINSID)
      TOP=2.515517+(0.802853*V)+(0.010328*V*V)
      BOTTOM=1.+(1.432788*V)+(0.189269*V*V)+(0.001308*V*V*V)
      VTERM=V-(TOP/BOTTOM)
      ABSRN=(RN-0.5)/(ABS(RN-0.5))
   30 TIME(M)=(XMEAN(M)/3600.)+(ABSRN*(STDDEV(M)/3600.)*VTERM)
      SUM20A=(1./MTBF(1))+(1./MTBF(2))+(1./MTBF(3))+(1./MTBF(4))+
MTB
     1F(5))+(1./MTBF(6))
      SUM20B=(1./MTBF(7))+(1./MTBF(9))+(1./MTBF(10))+(1./MTBF(11)
/M
     1TBF(12))+(1./MTBF(15))
      SUM20C=(1./MTBF(16))+(1./MTBF(18))+(1./MTBF(19))+(1./MTBF(2
/1
     1/MTBF(24))+(1./MTBF(29))
      RT(1,N)=DEXP(-1.*(SUM20A+SUM20B+SUM20C)*TIME(1))
      XMTBF(1)=1./(SUM20A+SUM20B+SUM20C)
      SUM21=SUM20A+SUM20B+SUM20C+(1./MTBF(14))
      RT(2,N)=DEXP(-1.*SUM21*TIME(2))
      XMTBF(2)=1./SUM21
      SUM22=SUM21+(1./MTBF(8))+(1./MTBF(27))
      RT(3,N)=DEXP(-1.*SUM22*TIME(3))
      XMTBF(3)=1./SUM22
      SUM23=SUM22+(1./MTBF(17))+(1./MTBF(20))+(1./MTBF(22))+(1./M

     1)+(1./MTBF(26))+(1./MTBF(28))
      RT(4,N)=DEXP(-1.*SUM23*TIME(4))
```

```
      XMTBF(5)=1./SUM24
      SUM25=SUM24
      SUM26=SUM25-(1./MTBF(14))
      RT(6,N)=DEXP(-1.*SUM26*TIME(6))
      XMTBF(6)=1./SUM26
      RT6N=RT(6,N)
      SUM27=SUM26
      RT(7,N)=DEXP(-1.*SUM27*TIME(7))
      XMTBF(7)=1./SUM27
      RT7N=RT(7,N)
      SUM28A=SUM27-(1./MTBF(3))-(1./MTBF(5))-(1./MTBF(11))-(1./MT
3))
      SUM28=SUM28A-(1./MTBF(17))-(1./MTBF(22))-(1./MTBF(23))-(1./
8)
     1)-(1./MTBF(12))
      RT(8,N)=DEXP(-1.*SUM28*TIME(8))
      XMTBF(8)=1./SUM28
      EL1A=(4./MTBF(41))+(4./MTBF(39))+(5./MTBF(45))+(5./MTBF(38)
/M
     1TBF(44))+(2./MTBF(53))+(2./MTBF(51))
      EL1B=(2./MTBF(49))+(6./MTBF(42))+(2./MTBF(50))+(2./MTBF(52)
/M
     1TBF(48))+(4./MTBF(47))+(1./MTBF(43))
      EL1=EL1A+EL1B
      EL2=(1./MTBF(45))+(1./MTBF(38))
      EL3=1./MTBF(53)
      EL4=1./MTBF(52)
      EL5=(1./MTBF(51))+(1./MTBF(49))
      EL6=(1./MTBF(45))+(1./MTBF(38))
      EL7=1./MTBF(50)
      EG1=(1./MTBF(53))+(8./MTBF(45))+(1./MTBF(46))+(1./MTBF(39))
/MT
     1BF(54))+(4./MTBF(42))+(1./MTBF(47))+(1./MTBF(48))
      EG2=(1./MTBF(45))+(1./MTBF(54))
      DO 32 K=1,8
      EXPL1=(DEXP(-1.*TIME(K)*EL1))*((3.-(2.*(DEXP(-1.*TIME(K)*EL
)**
     12.)*(3.-(2.*(DEXP(-1.*TIME(K)*EL3))))*(3.-(2.*(DEXP(-1.*TIM
*EL
     14))))
      EXPL2=(3.-(2.*(DEXP(-1.*TIME(K)*EL5))))*(2.-DEXP(-1.*TIME(K
6))
     1*(3.-(2.*(DEXP(-1.*TIME(K)*EL7))))
      RLOC(K)=EXPL1*EXPL2
      RGS(K)=DEXP(-1.*TIME(K)*EG1)*((3.-(2.*(DEXP(-1.*TIME(K)*EG2
**4
     1.)
      RGRND(K)=RLOC(K)*RGS(K)
   32 RT(K,N)=RT(K,N)*RGRND(K)
      RTAA(N)=RT(4,N)*RT(5,N)*RT(6,N)*RT(7,N)*RT(8,N)
      RTT(N)=RT(1,N)*RT(2,N)*RT(3,N)*RTAA(N)
      IF(ANS.EQ.0)GOTO 210
      CALL SAFETY
  210 DO 70 I=1,8
   70 SRT(I)=RT(I,N)-SRT(I)
      SRTAA=RTAA(N)-SRTAA
      SRTT=RTT(N)+SRTT
      IF(N.EQ.1)GOTO 100
      DO 80 I=1,8
   80 NUMAX(I)=DMAX1(RT(I,N),NUMAX(I))
      MAXRTA=DMAX1(RTAA(N),MAXRTA)
      MAXRTT=DMAX1(RTT(N),MAXRTT)
      GOTO 110
  100 DO 90 I=1,8
```

```
      MAXRTA=RTAA(N)
      MAXRTT=RTT(N)
      IF(N.EQ.1)GOTO 120
  110 DO 130 I=1,8
  130 NUMIN(I)=DMIN1(RT(I,N),NUMIN(I))
      MINRTA=DMIN1(RTAA(N),MINRTA)
      MINRTT=DMIN1(RTT(N),MINRTT)
      GOTO 40
  120 DO 140 I=1,8
  140 NUMIN(I)=RT(I,N)
      MINRTA=RTAA(N)
      MINRTT=RTT(N)
   40 CONTINUE
      DO 150 I=1,8
  150 MEAN(I)=SRT(I)/FLOAT(NLOOP)
      RTAAMN=SRTAA/FLOAT(NLOOP)
      RTTMN=SRTT/FLOAT(NLOOP)
      DO 160 N=1,NLOOP
      DO 170 I=1,8
      DIFRTM(I)=RT(I,N)-MEAN(I)
      IF(DIFRTM(I).LT.0.0000000000000000000001)GOTO 175
      DIF(I)=(RT(I,N)-MEAN(I))**2.
      GOTO 170
  175 DIF(I)=0.
  170 SUMDIF(I)=DIF(I)+SUMDIF(I)
      RTADIF=(RTAA(N)-RTAAMN)**2.
      RTTDIF=(RTT(N)-RTTMN)**2.
      RTASD=RTADIF+RTASD
      RTTSD=RTTDIF+RTTSD
  160 CONTINUE
      DO 180 I=1,8
  180 DEV(I)=DSQRT(SUMDIF(I)/(FLOAT(NLOOP)-1.))
      DEVRTA=DSQRT(RTASD/(FLOAT(NLOOP)-1.))
      DEVRTT=DSQRT(RTTSD/(FLOAT(NLOOP)-1.))
      PRINT*," "
      PRINT*," "
      PRINT*," "
      PRINT*,"                                  RELIABILITY ANALYSIS"
      PRINT*," "
      DO 190 I=1,8
      PRINT*," "
      PRINT*," "
      PRINT*," "
      PRINT*," "
      IF(I.EQ.1)PRINT*,"           LOC CAPTURE TO ARM G/S"
      IF(I.EQ.2)PRINT*,"           ARM G/S TO G/S CAPTURE"
      IF(I.EQ.3)PRINT*,"           G/S CAPTURE TO APPROACH ARM"
      IF(I.EQ.4)PRINT*,"           APPROACH ARM TO LAND ARM(100 FT

      IF(I.EQ.5)PRINT*,"       LAND ARM (100 FT) TO FLARE ENGAGE (
T)"
      IF(I.EQ.6)PRINT*,"         FLARE ENGAGE (45 FT) TO DECRAB (2
)"
      IF(I.EQ.7)PRINT*,"           DECRAB (20 FT) TO TOUCHDOWN"
      IF(I.EQ.8)PRINT*,"           TOUCHDOWN TO STOP"
      PRINT*," "
      PRINT*,"     MEAN TIME =                  ", XMEAN(I)
      PRINT*,"     STD.DEV.  OF TIME =          ", STDDEV(I)
      PRINT*,"     MTBF =                       ", XMTBF(I)
      PRINT*,"     VARIATION =                  ", XFER
      PRINT*,"     MEAN OF RELIABILITY =        ", MEAN(I)
      PRINT*,"     STD.DEV.  OF RELIABILITY =   ", DEV(I)
      PRINT*,"     MAX VALUE =                  ", NUMAX(I)
  190 PRINT*,"     MIN VALUE =                  ", NUMIN(I)
```

```
      PRINT*," "
      PRINT*,"                  TOTAL RELIABILITY FROM APPROACH ARM TO

      PRINT*," "
      PRINT*,"      MEAN OF RELIABILITY =       ", RTAAMN
      PRINT*,"      STD. DEV.  OF RELIABILITY = ", DEVRTA
      PRINT*,"      MAX VALUE =                 ", MAXRTA
      PRINT*,"      MIN VALUE =                 ", MINRTA
      PRINT*," "
      PRINT*," "
      PRINT*," "
      PRINT*," "
      PRINT*,"                  TOTAL RELIABILITY FOR COMPLETE MODEL"
      PRINT*," "
      PRINT*,"      MEAN OF RELIABILITY =       ", RTTMN
      PRINT*,"      STD. DEV.  OF RELIABILITY = ", DEVRTT
      PRINT*,"      MAX VALUE =                 ", MAXRTT
      PRINT*,"      MIN VALUE =                 ", MINRTT
      IF(ANS.EQ.0)GOTO 220
      PRINT*," "
      PRINT*," "
      PRINT*," "
      PRINT*," "
      PRINT*,"                              SAFETY ANALYSIS"
      DO 195 I=1,11
      PRINT*," "
      PRINT*," "
      PRINT*," "
      IF(I.EQ.1)PRINT*,"        SYSTEM OPERATIONAL"
      IF(I.EQ.2)PRINT*,"       NON-CRITICAL FAILURE AND SUCCESSFU
3A"
      IF(I.EQ.3)PRINT*,"   CRITICAL FAILURE TO SINGLE CHANNEL AND
     1SFUL R/GA"
      IF(I.EQ.4)PRINT*,"     WHEEL SPIN-UP NOT DETECTED AND SUCCE
_ R
     1/GA"
      IF(I.EQ.5)PRINT*,"      NON-CRITICAL FAILURE DURING ROLLOUT

      IF(I.EQ.6)PRINT*,"          BACK-UP ROLLOUT MODE"
      IF(I.EQ.7)PRINT*,"     CRITICAL FAILURE TO SINGLE CHANNEL D
3 R
     1OLLOUT"
      IF(I.EQ.8)PRINT*,"    LOCALIZER FAILURE AND SUCCESSFUL R/GA

      IF(I.EQ.9)PRINT*,"           SAFETY HAZARD"
      IF(I.EQ.10)PRINT*,"   ATTENUATED SAFETY HAZARD (NO PILOT VI
.IT
     1Y)"
      IF(I.EQ.11)PRINT*,"   ATTENUATED SAFETY HAZARD (LIMITED PIL
ISI
     1BILITY)"
      PRINT*," "
      PRINT*,"      PROBABILITY = ", PMEAN(I)
      PRINT*,"      STD. DEV.  =     ", PDEV(I)
      PRINT*,"      MAX VALUE =    ", PMAX(I)
      PRINT*,"      MIN VALUE =    ", PMIN(I)
  195 CONTINUE
  220 STOP
      END
      SUBROUTINE SAFETY
      DOUBLE PRECISION P40,RT6N,RT7N,PFAIL1,PFAIL2,PFAIL3,DEL(11)

      DOUBLE PRECISION EL18,RTEP(55),EL1,EL2,EL3,EL4,EL5,EL6,EL7,
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```
      DOUBLE PRECISION SUM26,SUM27,...
      DOUBLE PRECISION PMIN(11),RRGA(5),FED(3),PATH(46,100),G(3),
      DOUBLE PRECISION EXPL2,LOCR(3),P(11,100),AT(10),P1(10),PF1(
      DOUBLE PRECISION DPF(10),AT2(3),P2(3),PF2(3),SUMP(11),SUMDI
      DOUBLE PRECISION DIFF(11),RGA,FEDP,DTTP,DTT1,DTT2,DTT3,TDWS
      DOUBLE PRECISION TD2,TD3,TD4,TD5,PINS25,PINS1,PINS2,P27,PSH
      DOUBLE PRECISION P28A1,DPF2,DPF3,P28A2,P41(10),PF41(10)
      DOUBLE PRECISION DPF41(10),P41A1,P45A1,P41A(3),PF41A(3),DPF
      DOUBLE PRECISION DPF413,P41A2,P45A2,A1P40(10),A1CATS(10)
      DOUBLE PRECISION A2P40(3),A2CATS(3)
      COMMON MTBF,EL1,EL2,EL3,EL4,EL5,EL6,EL7,TIME,SUM26,SUM27,SU
      COMMON PMEAN,PDEV,PMAX,PMIN,N,NLOOP,RT6N,RT7N
      RGA=DEXP(-1.*(1./MTBF(30))*TIME(9))
      RRGA(1)=1.-(2.*RGA)+(RGA**2.)
      RRGA(2)=(2.*RGA)-(2.*RGA*RGA)
      RRGA(3)=RGA**2.
      RRGA(4)=1.-RGA
      RRGA(5)=RGA
      FEDP=DEXP(-1.*(1./MTBF(30))*TIME(6))
      FED(1)=1.-DEXP(-1.*(SUM26-(2.*(1./MTBF(30))))*TIME(6))
      FED(2)=2.*FEDP-(2.*(FEDP**2.))
      FED(3)=1.-(2.*FEDP)+(FEDP**2.)
      G(1)=TIME(6)
      G(2)=TIME(7)+(1./3600.)
      G(3)=TIME(8)-(1./3600.)
      DO 901 I=1,3
      EXPL1=(DEXP(-1.*G(I)*EL1))*((3.-(2.*(DEXP(-1.*G(I)*EL2))))*
     1.-(2.*(DEXP(-1.*G(I)*EL3))))*(3.-(2.*(DEXP(-1.*G(I)*EL4))))
      EXPL2=(3.-(2.*(DEXP(-1.*G(I)*EL5))))*(2.-DEXP(-1.*G(I)*EL6)
     12.*(DEXP(-1.*G(I)*EL7))))
  901 LOCR(I)=EXPL1*EXPL2
      PATH(1,N)=FED(1)*RRGA(1)
      PATH(2,N)=FED(1)*RRGA(2)
      PATH(3,N)=FED(1)*RRGA(3)
      PATH(4,N)=FED(2)*RRGA(4)
      PATH(5,N)=FED(2)*RRGA(5)
      PATH(6,N)=FED(3)
      PATH(7,N)=RT6N
      PFAIL1=1.-LOCR(1)
      PATH(30,N)=PATH(1,N)*PFAIL1
      PATH(31,N)=PATH(2,N)*PFAIL1
      PATH(32,N)=PATH(3,N)*PFAIL1
      PATH(33,N)=PATH(4,N)*PFAIL1
      PATH(34,N)=PATH(5,N)*PFAIL1
      PATH(35,N)=PATH(6,N)*PFAIL1
      PATH(36,N)-RT6N*RRGA(1)*PFAIL1
      PATH(37,N)=RT6N*RRGA(2)*PFAIL1
      PATH(38,N)=RT6N*RRGA(3)*PFAIL1
      DTTP=DEXP(-1.*(1./MTBF(30))*TIME(7))
      DTT1=1.-DEXP(-1.*(SUM27-(2.*(1./MTBF(30))))*TIME(7))
      DTT2=(2.*DTTP)-(2.*(DTTP**2.))
      DTT3=1.-(2.*DTTP)+(DTTP**2.)
      PATH(8,N)=DTT1*RRGA(1)
      PATH(9,N)=DTT1*RRGA(2)
```

```
      PATH(12,N)=DTT2*RRGA(5)
      PATH(13,N)=DTT3
      PATH(14,N)=RT7N
      TDWSF=DEXP(-1.*(1./MTBF(30))*(1./3600.))
      TD1=1.-DEXP(-1.*(SUM28-(2./MTBF(30))-(1./MTBF(31)))*(1./360

      TD2=(2.*TDWSF)-(2.*(TDWSF**2.))
      TD3=1.-(2.*TDWSF)+(TDWSF**2.)
      TD4=1.-DEXP(-1.*(1./MTBF(31))*(1./3600.))
      TD5=DEXP(-1.*SUM28*(1./3600.))
      PATH(15,N)=TD1*RRGA(1)
      PATH(16,N)=TD1*RRGA(2)
      PATH(17,N)=TD1*RRGA(3)
      PATH(18,N)=TD2*RRGA(4)
      PATH(19,N)=TD2*RRGA(5)
      PATH(20,N)=TD3
      PATH(21,N)=TD4*RRGA(1)
      PATH(22,N)=TD4*RRGA(2)
      PATH(23,N)=TD4*RRGA(3)
      PATH(24,N)=TD5
      PINS25=DEXP(-1.*(1./MTBF(32))*(TIME(8)-(1./3600.)))
      PINS1=(2.*PINS25)-(2.*(PINS25**2.))
      PINS2=1.-(2.*PINS25)+(PINS25**2.)
      PATH(25,N)=1.-DEXP(-1.*(SUM28-(1./MTBF(33)))*(TIME(8)-(1./3
)))
     1+PINS1+PINS2
      PATH(26,N)=1.-DEXP(-1.*(1./MTBF(34))*(TIME(8)-(1./3600.)))
      P27=DEXP(-1.*(1./MTBF(35))*(TIME(8)-(1./3600.)))
      PATH(27,N)=(2.*P27)-(2.*(P27**2.))
      PATH(28,N)=(1.-(2.*P27)+(P27**2.))+(1.-DEXP(-1.*(1./MTBF(36
TIM
     1E(8)-(1./3600.))))
      PATH(29,N)=DEXP(-1.*SUM28*(TIME(8)-(1./3600.)))
      DO 902 I=1,7
  902 PATH(I,N)=PATH(I,N)*LOCR(1)
      PFAIL2=1.-LOCR(2)
      PATH(39,N)=PFAIL2*(1.-DEXP(-1.*(SUM28+(1./MTBF(18))-(1./MTB
))))
     1*(TIME(8)-(1./3600.))))
      P40=DEXP(-1.*((1./MTBF(35))+(1./MTBF(32)))*(TIME(8)-(1./360
)
      PATH(40,N)=((2.*P40)-(2.*(P40**2.)))*PFAIL2
      PATH(41,N)=((1.-(2.*P40)+(P40**2.))+(1.-DEXP(-1.*(1./MTBF(2
*(TI
     1ME(8)-(1./3600.)))))*PFAIL2
      PATH(42,N)=PFAIL2*DEXP(-1.*SUM28*(TIME(8)-(1./3600.)))
      PFAIL3=1.-LOCR(3)
      PATH(43,N)=LOCR(2)*PFAIL3*PATH(39,N)
      PATH(44,N)=LOCR(2)*PFAIL3*PATH(40,N)
      PATH(45,N)=LOCR(2)*PFAIL3*PATH(41,N)
      PATH(46,N)=LOCR(2)*PFAIL3*PATH(42,N)
      DO 700 I=8,14
  700 PATH(I,N)=PATH(I,N)*PATH(7,N)
      DO 710 I=15,24
  710 PATH(I,N)=PATH(I,N)*PATH(14,N)
      DO 720 I=25,29
  720 PATH(I,N)=PATH(I,N)*PATH(24,N)*LOCR(2)*LOCR(3)
      DO 888 I=39,46
  888 PATH(I,N)=PATH(I,N)*PATH(24,N)
C     P(I,N),   I IS THE INDEX FOR 11 DIFFERENT PROBABILITIES TO BE CO

      P(1,N)=PATH(29,N)
      P(2,N)=PATH(2,N)-PATH(3,N)+PATH(9,N)-PATH(10,N)+PATH(16,N)+
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```
      P(5,N)=PATH(25,N)
      P(6,N)=PATH(26,N)+PATH(39,N)+PATH(42,N)+PATH(43,N)+PATH(46,
     1(40,N)+PATH(44,N)
      P(7,N)=PATH(27,N)
      PSH=PATH(1,N)+PATH(4,N)+PATH(6,N)+PATH(8,N)+PATH(11,N)+PATH
     1PATH(15,N)+PATH(18,N)+PATH(20,N)+PATH(21,N)+PATH(30,N)+PATH
     1PATH(35,N)+PATH(36,N)
      P(9,N)=PSH+PATH(28,N)+PATH(41,N)+PATH(45,N)
      P(8,N)=PATH(31,N)+PATH(32,N)+PATH(34,N)+PATH(37,N)+PATH(38,
C  ATTENUATION FUNCTION WITH NO PILOT VISIBILITY
      DT=TIME(8)-(21./3600.)
      AT(1)=5.
      AT(2)=6.9
      AT(3)=8.6
      AT(4)=10.2
      AT(5)=12.
      AT(6)=13.4
      AT(7)=14.9
      AT(8)=18.
      AT(9)=19.5
      AT(10)=21.
      DO 600 I=1,10
      P1(I)=DEXP(-1.*((1./MTBF(35))+(1./MTBF(26)))*((AT(I)/3600.)
      A1P40(I)=DEXP(-1.*((1./MTBF(35))+(1./MTBF(32)))*((AT(I)/360
T)
     1)
      A1CAT3(I)=1.-DEXP(-1.*(1./MTBF(26))*((AT(I)/3600.)+DT))
      P41(I)=A1P40(I)+A1CAT3(I)
      PF41(I)=1.-(2.*P41(I))+(P41(I)**2.)
  600 PF1(I)=(1.-(2.*P1(I))+(P1(I)**2.))+(1.-DEXP(-1.*(1./MTBF(36
(AT
     1(I)/3600.)+DT)))
      DO 610 I=2,10
      DPF41(I)=PF41(I)-PF41(I-1)
  610 DPF(I)=PF1(I)-PF1(I-1)
      P28A1=PF1(1)+(DPF(2)*.9)+(DPF(3)*.8)+(DPF(4)*.7)+(DPF(5)*.6
PF(
     16)*.4)+(DPF(7)*.2)+(DPF(8)*.1)+(DPF(9)*.05)
      P41A1=PF41(1)+(DPF41(2)*.9)+(DPF41(3)*.8)+(DPF41(4)*.7)+(DP
5)*
     1.6)+(DPF41(6)*.4)+(DPF41(7)*.2)+(DPF41(8)*.1)+(DPF41(9)*.05
      P45A1=P41A1
      P(10,N)=PSH+(P28A1*PATH(24,N)*LOCR(2)*LOCR(3))+(P41A1*PATH(
)*P
     1FAIL2)+(P45A1*PATH(24,N)*LOCR(2)*PFAIL3)
C  ATTENUATION FFNCTION WITH LIMITED PILOT VISIBILITY
      AT2(1)=3.
      AT2(2)=5.
      AT2(3)=6.9
      DO 620 I=1,3
      A2P40(I)=DEXP(-1.*((1./MTBF(35))+(1./MTBF(32)))*((AT2(I)/36
     1)
      A2CAT3(I)=1.-DEXP(-1.*(1./MTBF(26))*((AT2(I)/3600.)+DT))
      P41A(I)=A2P40(I)+A2CAT3(I)
      P2(I)=DEXP(-1.*(1./MTBF(35))*((AT2(I)/3600.)+DT))
      PF41A(I)=1.-(2.*P41A(I))+(P41A(I)**2.)
```

```
      [illegible]
      DFF2=FF2(2)-FF2(1)
      DFF3=FF2(3)-FF2(2)
      DFF412=FF41A(2)-FF41A(1)
      DFF413=FF41A(3)-FF41A(2)
      P28A2=FF2(1)+(DFF2*.6)+(DFF3*.1)
      P41A2=FF41A(1)+(DFF412*.6)+(DFF413*.1)
      P45A2=P41A2
      P(11,N)=PSH+(P28A2*FATH(24,N)*LOCR(2)*LOCR(3))+(P41A2*FATH(
)*F
     1FAIL2)*(P45A2*FATH(24,N)*LOCR(2)*PFAIL3)
      IF(N.GE.2)GOTO 7
      DO 630 I=1,11
      SUMP(I)=0.
  630 SUMDIP(I)=0.
    7 DO 640 I=1,11
  640 SUMP(I)=P(I,N)+SUMP(I)
      IF(N.EQ.1)GOTO 802
      DO 801 I=1,11
      PMAX(I)=DMAX1(P(I,N),PMAX(I))
  801 PMIN(I)=DMIN1(P(I,N),PMIN(I))
      GOTO 804
  802 DO 803 I=1,11
      PMAX(I)=P(I,N)
  803 PMIN(I)=P(I,N)
  804 IF(N.NE.NLOOP)GOTO 750
      DO 650 I=1,11
  650 PMEAN(I)=SUMP(I)/FLOAT(NLOOP)
      DO 660 J=1,NLOOP
      DO 670 I=1,11
      DEL(I)=P(I,J)-PMEAN(I)
      IF(DEL(I).LT.0.0000000000000000000001)GOTO 800
      DIFF(I)=(P(I,J)-PMEAN(I))**2.
      GOTO 670
  800 DIFF(I)=0.
  670 SUMDIP(I)=DIFF(I)+SUMDIP(I)
  660 CONTINUE
      DO 680 I=1,11
  680 PDEV(I)=DSQRT(SUMDIP(I)/(FLOAT(NLOOP)-1.))
  750 RETURN
      END
```

Reliability/Safety Analysis Results

(Category III Adapter System Configuration)

Run # 1

Did Not Vary Either Equipment MTBF
Or Segment Time Intervals

```
OXPER        = 0. 0,
OANS         = 1.
O$END
```

XPER = 0%

STD DEV. = 0.

```
                         RELIABILITY ANALYSIS



        LOC CAPTURE TO ARM G/S

   MEAN TIME =                    210.
   STD. DEV.  OF TIME =           0.
   MTBF =                         14. 082884571868752568475971
   VARIATION =                    0.
   MEAN OF RELIABILITY =          . 99586270431890024978121212
   STD. DEV.  OF RELIABILITY =    0.
   MAX VALUE =                    . 99586270431890024978121212
   MIN VALUE =                    . 99586270431890024978121212



        ARM G/S TO G/S CAPTURE

   MEAN TIME =                    30.
   STD. DEV.  OF TIME =           0.
   MTBF =                         13. 696532445454989180450208
   VARIATION =                    0.
   MEAN OF RELIABILITY =          . 999391225525913424011936182
   STD. DEV.  OF RELIABILITY =    0.
   MAX VALUE =                    . 999391225525913424011936183
   MIN VALUE =                    . 999391225525913424011936183



        G/S CAPTURE TO APPROACH ARM

   MEAN TIME =                    30.
   STD. DEV   OF TIME =           0.
   MTBF =                         13. 0108070314495826035939506
   VARIATION =                    0.
   MEAN OF RELIABILITY =          . 99935917887114048152942464
   STD. DEV.  OF RELIABILITY =    0.
   MAX VALUE =                    . 999359178871140481529424641
   MIN VALUE =                    . 999359178871140481529424641



        APPROACH ARM TO LAND ARM(100 FT)

   MEAN TIME =                    81. 54
   STD. DEV.  OF TIME =           0.
   MTBF =                         10. 4794439232769909088732488
   VARIATION =                    0.
   MEAN OF RELIABILITY =          . 997839513269738218015763749
   STD. DEV.  OF RELIABILITY =    0.
   MAX VALUE =                     99783951326973821801576375
   MIN VALUE =                     99783951326973821801576375
```

```
        LAND ARM (100 FT) TO FLARE ENGAGE (45 FT)

       MEAN TIME =                   5.35
       STD. DEV.  OF TIME =          0.
       MTBF =                        10.31109507084825401152145 77
       VARIATION =                   0.
       MEAN OF RELIABILITY =         .99985578790854371781415455
       STD. DEV.  OF RELIABILITY =   0.
       MAX VALUE =                   .99985578790854371781415455
       MIN VALUE =                   .99985578790854371781415455




          FLARE ENGAGE (45 FT) TO DECRAB (20 FT)

       MEAN TIME =                   3.07
       STD. DEV.  OF TIME =          0.
       MTBF =                        10.528542410466559210940364 8
       VARIATION =                   0.
       MEAN OF RELIABILITY =         .999918951950892512213143045
       STD. DEV.  OF RELIABILITY =   0.
       MAX VALUE =                   .999918951950892512213143046
       MIN VALUE =                   .999918951950892512213143046




             DECRAB (20 FT) TO TOUCHDOWN

       MEAN TIME =                   4.02
       STD. DEV.  OF TIME =          0.
       MTBF =                        10.528542410466559210940364 8
       VARIATION =                   0.
       MEAN OF RELIABILITY =         .999893873266497565505673998
       STD. DEV.  OF RELIABILITY =   0.
       MAX VALUE =                   .9998938732664975655056 74
       MIN VALUE =                   .9998938732664975655056 74




             TOUCHDOWN TO STOP

       MEAN TIME =                   22.73
       STD. DEV.  OF TIME =          0.
       MTBF =                        13.642208010011170998215618 1
       VARIATION =                   0.
       MEAN OF RELIABILITY =         .999536883013751858402459941
       STD. DEV.  OF RELIABILITY =   0.
       MAX VALUE =                   .999536883013751858402459941
       MIN VALUE =                   .999536883013751858402459941




               TOTAL RELIABILITY FROM APPROACH ARM TO STOP

       MEAN OF RELIABILITY =         .99704691456343466515740277
       STD. DEV.. OF RELIABILITY =   1.16705317994974666232604073E-27
       MAX VALUE =                   .997046914563434665157402771
       MIN VALUE =                   .997046914563434665157402771
```

```
                TOTAL RELIABILITY FOR COMPLETE MODEL

     MEAN OF RELIABILITY =       .991681473263029751090244356
     STD DEV. OF RELIABILITY = 1.01482885213021448897916585E-28
     MAX VALUE =                 .991681473263029751090244356
     MIN VALUE =                 .991681473263029751090244356



                            SAFETY ANALYSIS



        SYSTEM OPERATIONAL

     PROBABILITY = .999349986460438154086598134
     STD. DEV.   =    0.
     MAX VALUE   =  .999349986460438154086598134
     MIN VALUE   =  .999349986460438154086598134



       NON-CRITICAL FAILURE AND SUCCESSFUL R/GA

     PROBABILITY = .000202707182995918363858424733
     STD. DEV.   =    0.
     MAX VALUE   =  .000202707182995918363858424733
     MIN VALUE   =  .000202707182995918363858424733



   CRITICAL FAILURE TO SINGLE CHANNEL AND SUCCESSFUL R/GA

     PROBABILITY = .00000418854950139494397927334372
     STD. DEV.   =    0.
     MAX VALUE   =  .00000418854950139494397927334372
     MIN VALUE   =  .00000418854950139494397927334372



     WHEEL SPIN-UP NOT DETECTED AND SUCCESSFUL R/GA

     PROBABILITY = 5.02405502387034171250830551E-7
     STD. DEV.   =   0.
     MAX VALUE   =  5.02405502387034171250830552E-7
     MIN VALUE   =  5.02405502387034171250830552E-7



      NON-CRITICAL FAILURE DURING ROLLOUT

     PROBABILITY =  000400762796976050400164912103
     STD. DEV.   =    0.
     MAX VALUE   =  .000400762796976050400164912103
     MIN VALUE   =  .000400762796976050400164912103



          BACK-UP ROLLOUT MODE

     PROBABILITY = .00000415003889771518015386149116
```

```
          BACK-UP ROLLOUT MODE

     PROBABILITY = .00000415003889771518015386149116
     STD. DEV.  =     0.
     MAX VALUE =    .00000415003889771518015386149116
     MIN VALUE =    .00000415003889771518015386149116



     CRITICAL FAILURE TO SINGLE CHANNEL DURING ROLLOUT

     PROBABILITY = .00000461061499158315190036962373
     STD. DEV.  =     0.
     MAX VALUE =    .00000461061499158315190036962373
     MIN VALUE =    .00000461061499158315190036962373



    LOCALIZER FAILURE AND SUCCESSFUL R/GA

     PROBABILITY = 3.5731472942221270467460677 3E-8
     STD. DEV.  =     0.
     MAX VALUE =    3.5731472942221270467460677 3E-8
     MIN VALUE =    3.5731472942221270467460677 3E-8



           SAFETY HAZARD

     PROBABILITY = .00003281544511790692570161 25297
     STD. DEV.  =     0.
     MAX VALUE =    .00003281544511790692570161 25298
     MIN VALUE =    .00003281544511790692570161 25298



   ATTENUATED SAFETY HAZARD (NO PILOT VISIBILITY)

     PROBABILITY = .00002000247260482383222655 40776
     STD. DEV.  =     0.
     MAX VALUE =    .00002000247260482383222655 40776
     MIN VALUE =    .00002000247260482383222655 40776



   ATTENUATED SAFETY HAZARD (LIMITED PILOT VISIBILITY)

     PROBABILITY = .00000924219495092764683286795945
     STD. DEV.  =     0.
     MAX VALUE =    .00000924219495092764683286795946
     MIN VALUE =    .00000924219495092764683286795946
*EOR
1  CSB     NOS/BE L414H ECS    CYBR CMR3 05/30/77
 10.57.38.FATIASD  FROM     /IA
 10.57.38.IP  00000128 WORDS - FILE INPUT     DC 00
 10.57.38.FAT(T25,I050,CM100000,STCSB) D760276,BUS
 10.57.38.SINGER,UD,229-4238
 10.57.40.ATTACH(LGO,AWLS2BIN,CY=1)
 10.57.40.MAP(PART)
 10.57.41.LGO.
 10.57.55.     STOP
 10.57.55.      2.879 CP SECONDS EXECUTION TIME
 10.57.56.OP  00001600 WORDS - FILE OUTPUT ,  DC 40
```

Run # 2

Only Varied Equipment MTBF

λ_{PGR} = 10%
STD. DEV. = 0.

RELIABILITY ANALYSIS

LOC CAPTURE TO ARM G/S

```
MEAN TIME =                   210.
STD. DEV.  OF TIME =          0.
MTBF =                        14. 3130805087208055892715133
VARIATION =                   . 1
MEAN OF RELIABILITY =         . 9958494302887408293712833 68
STD. DEV.  OF RELIABILITY =   . 000068256323737397467962216 3624
MAX VALUE =                   . 9960882714151226423056021 99
MIN VALUE =                   . 9956490179133931702730414 8
```

ARM G/S TO G/S CAPTURE

```
MEAN TIME =                   30.
STD. DEV.  OF TIME =          0.
MTBF =                        13. 9025863582393155369438416
VARIATION =                   . 1
MEAN OF RELIABILITY =         . 999389132475422343578429 08
STD. DEV.  OF RELIABILITY =   . 00000980996067547401205019762645
MAX VALUE =                   . 9994220832695318051545685 42
MIN VALUE =                   . 9993608216502363463679872 65
```

G/S CAPTURE TO APPROACH ARM

```
MEAN TIME =                   30.
STD. DEV.  OF TIME =          0.
MTBF =                        13. 1378723805566057175275343
VARIATION =                   . 1
MEAN OF RELIABILITY =         . 9993569878749828096495037 68
STD. DEV.  OF RELIABILITY =   . 00001002727404126228190331 77332
MAX VALUE =                    9993909635720050084813374 38
MIN VALUE =                   . 9993274033211862512526569 31
```

APPROACH ARM TO LAND ARM(100 FT)

```
MEAN TIME =                   81. 54
STD. DEV.  OF TIME =          0.
MTBF =                        10. 5354626831567483740110429
VARIATION =                   . 1
MEAN OF RELIABILITY =         . 9978316970507477396051863 16
STD. DEV.  OF RELIABILITY =   . 00002846444184122234094970237077
MAX VALUE =                   . 9979458190081003192878947
MIN VALUE =                   . 9977323265928674830552652 82
```

```
      LAND ARM (100 FT) TO FLARE ENGAGE (45 FT)

     MEAN TIME =                    5.35
     STD.DEV.  OF TIME =            0.
     MTBF =                         10.4058154948726318925920006
     VARIATION =                    .1
     MEAN OF RELIABILITY =          .9998552699472239559468882263
     STD.DEV.  OF RELIABILITY =     .00000185651299718871121720886191
     MAX VALUE =                    .999862607457916075955253195
     MIN VALUE =                    .999848562729291597083468824




        FLARE ENGAGE (45 FT) TO DECRAB (20 FT)

     MEAN TIME =                    3.07
     STD.DEV.  OF TIME =            0.
     MTBF =                         10.6340885497214814401324082
     VARIATION =                    .1
     MEAN OF RELIABILITY =          .999918674108690615315188418
     STD.DEV.  OF RELIABILITY =     .00000106474855476465422378935295
     MAX VALUE =                    .999923016706548769664860134
     MIN VALUE =                    .999914897562825376859151599




           DECRAB (20 FT) TO TOUCHDOWN

     MEAN TIME =                    4.02
     STD.DEV.  OF TIME =            0.
     MTBF =                         10.6340885497214814401324082
     VARIATION =                    .1
     MEAN OF RELIABILITY =          .999893509456658361319027732
     STD.DEV.  OF RELIABILITY =     .00000139419617264964518107770683
     MAX VALUE =                    .999899195715410066510583088
     MIN VALUE =                    .999888564399708329500467327




           TOUCHDOWN TO STOP

     MEAN TIME =                    22.73
     STD.DEV.  OF TIME =            0.
     MTBF =                         13.8668929527995460397317803
     VARIATION =                    .1
     MEAN OF RELIABILITY =          .999535238635083240729716539
     STD.DEV.  OF RELIABILITY =     .00000793911473797534805627658489
     MAX VALUE =                    .999562831558650830379405866
     MIN VALUE =                    .999511831544802549123805509




             TOTAL RELIABILITY FROM APPROACH ARM TO STOP

     MEAN OF RELIABILITY =          .997036308691664054970897923
     STD.DEV.  OF RELIABILITY =     .0000563674824800689772774196798
     MAX VALUE =                    .997195185516212737490546184
     MIN VALUE =                    .996902150735689602483778503
```

```
              TOTAL RELIABILITY FOR COMPLETE MODEL

      MEAN OF RELIABILITY =       .99165346647129635114871739 4
      STD. DEV.  OF RELIABILITY = .00017686956911181057695794895
      MAX VALUE =                 .992115784257176636348917964
      MIN VALUE =                 .991277300139597408108815358



                         SAFETY ANALYSIS



         SYSTEM OPERATIONAL

      PROBABILITY = .99934770138224053967681549 8
      STD. DEV.  =    .000010311016284524559002855210 9
      MAX VALUE =    .99938532675993083271857231 4
      MIN VALUE =    .99931789042342953502872585 4



        NON-CRITICAL FAILURE AND SUCCESSFUL R/GA

      PROBABILITY = .00020343926436147368814115125 7
      STD. DEV.  =    .00000277464650541683833437667 2
      MAX VALUE =    .00021255207709269514364197879 2
      MIN VALUE =    .00019231851877125461892637111 4



  CRITICAL FAILURE TO SINGLE CHANNEL AND SUCCESSFUL R/GA

      PROBABILITY = .0000041724904637853592815626016 1
      STD. DEV.  =    1.7559136477679869090384123 2E-7
      MAX VALUE =    .0000046442723828956696475058124 1
      MIN VALUE =    .0000038218612557935732033194009 9



      WHEEL SPIN-UP NOT DETECTED AND SUCCESSFUL R/GA

      PROBABILITY = 5.0007845116175946939278615 5E-7
      STD. DEV.  =    2.0928098579120075947939694 6E-8
      MAX VALUE =    5.5730036544102592577075684 2E-7
      MIN VALUE =    4.5940609366115814540465214 3E-7



       NON-CRITICAL FAILURE DURING ROLLOUT

      PROBABILITY = .00040201350565849517386954376 4
      STD. DEV.  =    .000007381323829465550022310569 03
      MAX VALUE =    .00042562444682938467105416569 14
      MIN VALUE =    .00037076434710461095989084404 1



            BACK-UP ROLLOUT MODE

      PROBABILITY = .0000041642255380250191438448203 9
```

```
               BACK-UP ROLLOUT MODE

        PROBABILITY = .00000416422553802501914384482039
        STD. DEV.  =     1.856324311471208562717252223E-7
        MAX VALUE =    .00000460116022041149312424612218
        MIN VALUE =    .00000378570603948040369958903803



        CRITICAL FAILURE TO SINGLE CHANNEL DURING ROLLOUT

        PROBABILITY = .00000460547295156560874999725938
        STD. DEV.  =     1.969771060503941492893372 1E-7
        MAX VALUE =    .00000511738679841756783630954031
        MIN VALUE =    .00000419208293122133648485963778



       LOCALIZER FAILURE AND SUCCESSFUL R/GA

        PROBABILITY = 3.579877392995151641270083 77E-8
        STD. DEV.  =     1.246842922370014701516971 09E-9
        MAX VALUE =    3.916856774608437324913879 93E-8
        MIN VALUE =    3.281095861015172515122951 35E-8



               SAFETY HAZARD

        PROBABILITY = .00003268095525401824967862 79886
        STD. DEV.  =     .00000139367580029720519611705339
        MAX VALUE =    .00003637535520601469811025 76679
        MIN VALUE =    .00002990170369742619998559 55662



      ATTENUATED SAFETY HAZARD (NO PILOT VISIBILITY)

        PROBABILITY = .00001992050130789874436038 32449
        STD. DEV.  =     8.494904531302257676934194 68E-7
        MAX VALUE =    .00002217233556300431730466 16065
        MIN VALUE =    .00001822647832957229344468 95812



      ATTENUATED SAFETY HAZARD (LIMITED PILOT VISIBILITY)

        PROBABILITY = .00000920431691777003052931 543882
        STD. DEV.  =     3.925217354544097090755313 99E-7
        MAX VALUE =    .00001024482664523348570135 6131
        MIN VALUE =    .00000842155564345798154140 280838
*EOR
1  CSB     NOS/BE L414H ECS    CYBR CMR3 R.D 14.18
 14.23.54.FATIAFN  FROM     /IA
 14.23.54.IP   00000256 WORDS - FILE INPUT  , DC 00
 14.23.54.FAT(T25,I050,CM100000,STCSB) D760276,BUS
 14.23.54.SINGER,UD,229-4238
 14.24.03.ATTACH(LGO,AWLS2BIN,CY=1)
 14.24.04.MAP(PART)
 14.24.05.LGO.
 14.26.58.       STOP
 14.26.58.        2.907 CP SECONDS EXECUTION TIME
 14.26.58.OP   00001664 WORDS - FILE OUTPUT , DC 40
 14.26.58.MS      3584  WORDS  (      3584 MAX USED)
 14.26.58.CPM  100000   WORDS MAXIMUM
```

.00008 [illegible]

Run # 3

Only Varied Segment Time Intervals

AWLS2

XPER = 0%

STDDEV. = vary

RELIABILITY ANALYSIS

LOC CAPTURE TO ARM G/S

MEAN TIME =	210.
STD. DEV. OF TIME =	0.
MTBF =	14.082884571868752568475971
VARIATION =	0.
MEAN OF RELIABILITY =	.9958627043189002497812121 2
STD. DEV. OF RELIABILITY =	0.
MAX VALUE =	.99586270431890024978121212
MIN VALUE =	.99586270431890024978121212

ARM G/S TO G/S CAPTURE

MEAN TIME =	30.
STD. DEV. OF TIME =	0.
MTBF =	13.696532443454989180450208
VARIATION =	0.
MEAN OF RELIABILITY =	.99939122552591342401193618 2
STD. DEV. OF RELIABILITY =	0.
MAX VALUE =	.999391225525913424011936183
MIN VALUE =	.999391225525913424011936183

G/S CAPTURE TO APPROACH ARM

MEAN TIME =	30.
STD. DEV. OF TIME =	0.
MTBF =	13.010807031449582603593950 6
VARIATION =	0.
MEAN OF RELIABILITY =	.999359178871140481529424 64
STD. DEV. OF RELIABILITY =	0.
MAX VALUE =	.99935917887114048152942464 1
MIN VALUE =	.99935917887114048152942464 1

APPROACH ARM TO LAND ARM(100 FT)

MEAN TIME =	81.54
STD. DEV. OF TIME =	1.95
MTBF =	10.47944392132769909088732488
VARIATION =	0.
MEAN OF RELIABILITY =	.9978436630974400062673492567
STD. DEV. OF RELIABILITY =	.00006290421711130484758741990335
MAX VALUE =	.9979500010514573209898432981
MIN VALUE =	.99773237339613753354579477

```
MEAN TIME =                     5.35
STD. DEV.  OF TIME =            .42
MTBF =                          10.3110950708482540115214577
VARIATION =                     0.
MEAN OF RELIABILITY =           .9998555794613307678160825O9
STD. DEV.  OF RELIABILITY =     .00000720975937230332924814289794
MAX VALUE =                     .999881990465313858713826823
MIN VALUE =                     .999831790470495383665966684


      FLARE ENGAGE (45 FT) TO DECRAB (20 FT)

MEAN TIME =                     3.07
STD. DEV.  OF TIME =            .33
MTBF =                          10.5285424104665592109403648
VARIATION =                     0.
MEAN OF RELIABILITY =           .999920547546234108541327782
STD. DEV.  OF RELIABILITY =     .00000556878357694219237069695121
MAX VALUE =                     .999939401092994245929606076
MIN VALUE =                     .999903745542622390335023668


        DECRAB (20 FT) TO TOUCHDOWN

MEAN TIME =                     4.02
STD. DEV.  OF TIME =            .33
MTBF =                          10.5285424104665592109403648
VARIATION =                     0.
MEAN OF RELIABILITY =           .999893901374475084722544419
STD. DEV.  OF RELIABILITY =     .0000049806099218790561463420569
MAX VALUE =                     .999914216781577947322713019
MIN VALUE =                     .99987903374153604068331222


        TOUCHDOWN TO STOP

MEAN TIME =                     22.73
STD. DEV.  OF TIME =            .53
MTBF =                          13.6422080100111709982156181
VARIATION =                     0.
MEAN OF RELIABILITY =           .999536048708488279827033334
STD. DEV.  OF RELIABILITY =     .00000623793966163493295342306487
MAX VALUE =                     .999557493590003968665974326
MIN VALUE =                     .999516230763294734828804829


          TOTAL RELIABILITY FROM APPROACH ARM TO STOP

MEAN OF RELIABILITY =           .997053606363009723637702349
STD. DEV.  OF RELIABILITY =     .0000450B53101825930665035689661
MAX VALUE =                     .997162066234342112894566897
MIN VALUE =                     .99693949172223848575290235
```

```
MEAN OF RELIABILITY =       .99168812905180402416127295
STD. DEV.  OF RELIABILITY = .0000448426911224847784753382563
MAX VALUE =                 .99179600526446942059221 2125
MIN VALUE =                 .99157462849989624355438 5208
```

SAFETY ANALYSIS

SYSTEM OPERATIONAL

```
PROBABILITY = .99935077495227102397575601 9
STD. DEV.  =   .000009070779442343249299665674442
MAX VALUE =    .99938794351148778784903505 8
MIN VALUE =    .99930932857237281593209490 7
```

NON-CRITICAL FAILURE AND SUCCESSFUL R/GA

```
PROBABILITY = .000201116606648448436460779118
STD. DEV.  =   .0000076695285953502366856403717 6
MAX VALUE =    .000226727078406733040045856736
MIN VALUE =    .000175891696151926881862525 61
```

CRITICAL FAILURE TO SINGLE CHANNEL AND SUCCESSFUL R/GA

```
PROBABILITY = .0000041567080069587771078301495 5
STD. DEV.  =   1.3354147895016320758567734 8E-7
MAX VALUE =    .0000046694232056593181106940183 9
MIN VALUE =    .0000036517143446413318189137608 9
```

WHEEL SPIN-UP NOT DETECTED AND SUCCESSFUL R/GA

```
PROBABILITY = 5.02406318019390926949268814E-7
STD. DEV.  =   3.95470188035376530321004725E-12
MAX VALUE =    5.02419249855355746568201815E-7
MIN VALUE =    5.02393187748003015488778519E-7
```

NON-CRITICAL FAILURE DURING ROLLOUT

```
PROBABILITY = .000401518698030303744875188195
STD. DEV.  =   .0000057190338006728884528643623 5
MAX VALUE =    .000419464465552286132920681065 6
MIN VALUE =    .000382105632372945863031256378
```

BACK-UP ROLLOUT MODE

```
PROBABILITY = .0000041377493314833583279940946 4
STD. DEV.  =   5.8302793176726926901914339E-8
MAX VALUE =    .0000043396304654130017957810673 1
MIN VALUE =    .0000038995276918493914328215323 9
```

```
      CRITICAL FAILURE TO SINGLE CHANNEL DURING ROLLOUT

        PROBABILITY = .00000461931334575595194588576368
        STD. DEV.  =     6.58080292076122737244538975E-8
        MAX VALUE =    .00000482581541924355270565909147
        MIN VALUE =    .00000439593266483882371613826322



      LOCALIZER FAILURE AND SUCCESSFUL R/GA

        PROBABILITY = 3.50280107846044730330866148E-8
        STD. DEV.  =     2.395129823461705674333149764E-9
        MAX VALUE =    4.24358296815451982725053807E-8
        MIN VALUE =    2.67158161789222138200373996E-8




              SAFETY HAZARD

        PROBABILITY = .0000328773534987503181535723578
        STD. DEV.  =     4.683737252052227320442144E-7
        MAX VALUE =    .0000343470844966541519794351715
        MIN VALUE =    .000031287490806042251633544332



     ATTENUATED SAFETY HAZARD (NO PILOT VISIBILITY)

        PROBABILITY = .0000200643642884414819220526373
        STD. DEV.  =     4.68372836748107496205444095E-7
        MAX VALUE =    .0000215339876933890654917841086
        MIN VALUE =    .0000184744371571344861163289356



     ATTENUATED SAFETY HAZARD (LIMITED PILOT VISIBILITY)

        PROBABILITY = .00000930406651358467627285692434
        STD. DEV.  =     4.68332139938023583564272151E-7
        MAX VALUE =    .0000107734722091827825723627051
        MIN VALUE =    .0000077142146751771906945960579
*EOR
1  CSB     NOS/BE L414H ECS    CYBR CMR3 05/30/77
 14.00.32.FATIAFC  FROM     /IA
 14.00.32.IP   00000256 WORDS - FILE INPUT  , DC 00
 14.00.32.FAT(T25,1050,CM100000,STCSB) D760276,BUS
 14.00.32.SINGER,WD,229-4238
 14.00.34.ATTACH(LGO,AWLS2BIN,CY=1)
 14.26.00.MAP(PART)
 14.26.00.LGO.
 14.27.33.     STOP
 14.27.33.      2.850 CP SECONDS EXECUTION TIME
 14.27.33.OP  00001664 WORDS - FILE OUTPUT , DC 40
 14.27.33.MS     3584  WORDS  (     3584 MAX USED)
 14.27.33.ECM 100000  WORDS MAXIMUM
 14.27.33.CPA         3.822 SEC.          1.659 ADJ.
 14.27.33.IO          1.240 SEC.           .620 ADJ.
 14.27.33.CM        123.604 KWS.          1.004 ADJ.
 14.27.33.CPUS                            3.284
 14.27.33.COST                 $           .19
 14.27.33.PP          3.577 SEC.       DATE 07/20/77
 14.27.33.EJ  END OF JOB, IA  D760276.
```

Run # 4

Varied Both Equipment MTBF
and Segment Time Intervals

XPER = 10%
STD. DEV. = [illegible]

```
LOC CAPTURE TO ARM G/S

MEAN TIME =                   210.
STD. DEV.  OF TIME =          0.
MTBF =                        14. 313080508720805589271513 3
VARIATION =                   . 1
MEAN OF RELIABILITY =         . 9958494302887408297128336 8
STD. DEV.  OF RELIABILITY =   . 0000682563237373974679622163624
MAX VALUE =                   . 99608827141512264230560219 9
MIN VALUE =                   . 9956490179133931702730414 8


ARM. G/S TO G/S CAPTURE

MEAN TIME =                   30.
STD. DEV.  OF TIME =          0.
MTBF =                        13. 9025863582393155369438416
VARIATION =                   . 1
MEAN OF RELIABILITY =         . 99938913247542234357842908
STD. DEV.  OF RELIABILITY =   . 000009809960675474012050197 62645
MAX VALUE =                   . 99942208326953180515456854 2
MIN VALUE =                   . 99936082165023634636798726 5


G/S CAPTURE TO APPROACH ARM

MEAN TIME =                   30.
STD. DEV.  OF TIME =          0.
MTBF =                        13. 13787238055660571752753 43
VARIATION =                   . 1
MEAN OF RELIABILITY =         . 99935698787498280964950376 8
STD. DEV.  OF RELIABILITY =   . 0000100272740412622819033177332
MAX VALUE =                   . 99939096357200500848133743 8
MIN VALUE =                   . 99932740332118625125265693 1


APPROACH ARM TO LAND ARM(100 FT)

MEAN TIME =                   81. 54
STD. DEV.  OF TIME =          1. 95
MTBF =                        10. 585462683156748374011042 9
VARIATION =                   . 1
MEAN OF RELIABILITY =         . 99783798728532025318950689 4
STD. DEV.  OF RELIABILITY =   . 00003778744751389111556964 38087
MAX VALUE =                   . 99795527857788919340186873
MIN VALUE =                   . 9976880666576820849695667


LAND ARM (100 FT) TO FLARE ENGAGE (45 FT)

MEAN TIME =                   5. 35
```

```
LAND ARM (100 FT) TO FLARE ENGAGE (45 FT)

MEAN TIME =                    5.35
STD. DEV.  OF TIME =           .42
MTBF =                         10.40581549487263189259200 06
VARIATION =                    .1
MEAN OF RELIABILITY =          .99985506604765986940154 0986
STD. DEV.  OF RELIABILITY =    .00000743073018325982825690335407
MAX VALUE =                    .99988331397255046305447 9852
MIN VALUE =                    .99983092509718753059988 1412


FLARE ENGAGE (45 FT) TO DECRAB (20 FT)

MEAN TIME =                    3.07
STD. DEV.  OF TIME =           .33
MTBF =                         10.6340885497214814401324082
VARIATION =                    .1
MEAN OF RELIABILITY =          .99992028431452707208839 2829
STD. DEV.  OF RELIABILITY =    .00000568699394856722672864200335
MAX VALUE =                    .99993912082417427153759 4056
MIN VALUE =                    .99990202184220598124048 5169


DECRAB (20 FT) TO TOUCHDOWN

MEAN TIME =                    4.02
STD. DEV.  OF TIME =           33
MTBF =                         10.6340885497214814401324082
VARIATION =                    .1
MEAN OF RELIABILITY =          .99989352265588670039463 5736
STD. DEV.  OF RELIABILITY =    .00000536793511109932596157153675
MAX VALUE =                    .99991434044394648566685 1277
MIN VALUE =                    .99987636608763551615042 81176


TOUCHDOWN TO STOP

MEAN TIME =                    22.73
STD. DEV.  OF TIME =           53
MTBF =                         13.8668929527995460397317803
VARIATION =                    .1
MEAN OF RELIABILITY =          .99953437669322093196696 0382
STD. DEV.  OF RELIABILITY =    .00001076109560073688673932 56142
MAX VALUE =                    .99957093765449232587721 9945
MIN VALUE =                    .99949623423756995869104 6245


TOTAL RELIABILITY FROM APPROACH ARM TO STOP

MEAN OF RELIABILITY =          .99704309950755981520188 8556
STD. DEV.  OF RELIABILITY =    .00006839519157859784710825 54214
MAX VALUE =                    .99722500237363883594501 0427
MIN VALUE =                    .99687751985421087051432 3104
```

```
             TOTAL RELIABILITY FOR COMPLETE MODEL

MEAN OF RELIABILITY =          .991660218426789376414068666
STD. DEV.  OF RELIABILITY = .000178569424040598226387911906
MAX VALUE =                    .992078231481461317970334367
MIN VALUE =                    .99126558004041251581148117



                         SAFETY ANALYSIS



    SYSTEM OPERATIONAL

PROBABILITY = .999348461930387827640081317
STD. DEV.  =    .00001464963004838847113458413202
MAX VALUE =    .999397553192035063581056199
MIN VALUE =    .999299008442766922298054749



   NON-CRITICAL FAILURE AND SUCCESSFUL R/GA

PROBABILITY = .000201847514481479267807883652
STD. DEV.  =    .00000805010225588591630637756329
MAX VALUE =    .000228036415699239010303879175
MIN VALUE =    .000174434757590670444026206213



CRITICAL FAILURE TO SINGLE CHANNEL AND SUCCESSFUL R/GA

PROBABILITY = .00000414214452432271369911502239
STD. DEV.  =   2.52524700975513096763710426E-7
MAX VALUE =    .00000501056265786199491860458421
MIN VALUE =    .00000350537993594147182816317901



WHEEL SPIN-UP NOT DETECTED AND SUCCESSFUL R/GA

PROBABILITY = 5.00079302672483344889263895E-7
STD. DEV.  =   2.09287991393052967406993831E-8
MAX VALUE =    5.57303135267269994129881264E-7
MIN VALUE =    4.5941249651570681488034695E-7



  NON-CRITICAL FAILURE DURING ROLLOUT

PROBABILITY = .000402798934259630453381627348
STD. DEV.  =    .00000975219370644601285568167931
MAX VALUE =    .00043682562723761833401016501
MIN VALUE =    .000367430979077755926006974318



      BACK-UP ROLLOUT MODE

PROBABILITY = .00000417202937972974006328512277
STD. DEV.  =   1.94742164150455024096121137E-7
MAX VALUE =    .0000047132365064626669331978578
```

```
CRITICAL FAILURE TO SINGLE CHANNEL DURING ROLLOUT

  PROBABILITY =  .00000461395352207721008010767186
  STD. DEV.   =    2.0551201113986038823059677E-7
  MAX VALUE   =   .00000519170199513333145409433632
  MIN VALUE   =   .00000412861098360290379500162523



LOCALIZER FAILURE AND SUCCESSFUL R/GA

  PROBABILITY = 3.50949876180129591887277136E-8
  STD. DEV.   =    2.72621996073851981636721798E-9
  MAX VALUE   =    4.40873842719240909743807979E-8
  MIN VALUE   =    2.52943013608305457402452179E-8
```

Table
Sensitivity Analysis Results

```
      SAFETY HAZARD

  PROBABILITY = .0000327438166021570361101459344
  STD. DEV.   =   .00000150198422787008280541168935
  MAX VALUE   =   .0000379455922942719968971047685
  MIN VALUE   =   .0000292595644561550105540838004



ATTENUATED SAFETY HAZARD (NO PILOT VISIBILITY)

  PROBABILITY = .0000199333454810879511949723643
  STD. DEV.   =   .00000100096181976870049564397842
  MAX VALUE   =   .0000237838471061538688639588685
  MIN VALUE   =   .0000175542796299228743688370081



ATTENUATED SAFETY HAZARD (LIMITED PILOT VISIBILITY)

  PROBABILITY = .00000926714074562744832560886392
  STD. DEV.   =   6.33662839584527614425351817E-7
  MAX VALUE   =   .0000118907612696732920246567859
  MIN VALUE   =   .00000750290686946635884223821882
EOR
1   CSB      NOS/BE L414H ECS    CYBR CMRS 05/30/77
12.00.43 FATIA5X  FROM     /IA
12.00.43.IF  00000128 WORDS - FILE INPUT  , DC 00
12.00.43.FAT(T25,I050,CM100000,STCSB) D760276,BUS
12.00.43.SINGER,UD,229-4238
12.00.44.ATTACH,A,AWLS2,CY=1.
12.00.45.FTN,I=A,T,L=0.
12.01.51.      14.719 CP SECONDS COMPILATION TIME
12.01.51.MAP(PART)
12.01.51.LGO.
12.02.01.      STOP
12.02.01.       2.975 CP SECONDS EXECUTION TIME
12.02.01.OF  00001792 WORDS - FILE OUTPUT , DC 40
12.02.01.MS   32256  WORDS  (   32256 MAX USED)
12.02.01.SCM 100000  WORDS MAXIMUM
12.02.01.CPA      13.820 SEC.          5.169 ADJ.
12.02.01.IO        6.363 SEC.          3.183 ADJ.
12.02.01.CM      599.034 KWS.          4.793 ADJ.
12.02.01.CRUS                         16.146
12.02.01.COST                  $        .96
```

1.00002756

Program Listing For Reliability/Safety Analysis
(STACC System Configuration)

```
3 343 OF SECONDS COMPILATION TIME
LGO, LGO, AWLS3BIN, RF=999

CLE CATALOG
=  D760276 PFN=AWLS3BIN
= 002  00004736 WORDS.
E(  )M1, AWLS3BIN, CY=1

= . D760276 PFN=AWLS3BIN
= 001  00004736 WORDS.
ME, LGO, AWLS3BIN, CY=1, RF=999

=  D760276 PFN=AWLS3BIN
= 002  00004736 WORDS.
=  D760276 PFN=AWLS3BIN
= 001  00004736 WORDS.
CH, CARDS

S

CLE NO.  = 001
RDS, S
```

Listing of AWLS3

7-20-77

AWLS3
XPER=0
σ = vary

```
=PAT(T25, I050, CM100000, STCSB) D760276, BUSSINGER, UD, 229-4238
=ATTACH(LGO, AWLS3BIN, CY=1)
=MAP(PART)
=LGO.
=(  )R
= $AWLS NL=100, XPER=0. , ANS=1$
H, CARDS, INPUT, HERE
```

Listing of cards

XPER= 0%

```
S

L FILES--
S     *A3        *A2        AWLS3      AWLS2
      $INPUT     $OUTPUT    *LGO       DUM1
TE INPUT FILES--
AGL
TE OUTPUT FILES--
AEI   PATIAFC
```

LISTING OF AWLS3

σ: vary

XPER = 0%

A3

4

```
      PROGRAM AWLS3 (INPUT,OUTPUT)
      DOUBLE PRECISION NUMAX(8),NUMIN(8),MAXRTA,MAXRTT,MINRTA,MIN

      DOUBLE PRECISION DIFRTM(10),DIF(8),SUMDIF(8),RTADIF,RTTDIF,
D
      DOUBLE PRECISION RTTSD,DEV(8),DEVRTA,DEVRTT,EL1A,EL1B,EG1,E

      DOUBLE PRECISION EXPL1,EXPL2,EL1,EL2,EL3,EL4,EL5,EL6,EL7,MT
(2)
      DOUBLE PRECISION TIME(9),SUM26,SUM27,SUM28,RT(8,100),PMEAN(

      DOUBLE PRECISION PDEV(11),PMAX(11),PMIN(11),SRT(8),MEAN(8)
      DOUBLE PRECISION RTT(100),RTAA(100),XMTBF(8),SRTT,SRTAA,VIN

      DOUBLE PRECISION V,TOP,BOTTOM,VTERM,ABSRN,SUM20A,SUM20B,SUM

      DOUBLE PRECISION SUM21,SUM22,SUM23,SUM24,SUM25,SUM28A,RTAAM
TMN
      DOUBLE PRECISION RLOC(8),RGS(8),RGRND(8),RT6N,RT7N
      REAL XMEAN(9),STDDEV(9),INS,MCC,NAVREC,NAVSEL,EQUIP(52)
      COMMON MTBF,EL1,EL2,EL3,EL4,EL5,EL6,EL7,TIME,SUM26,SUM27,SU

      COMMON PMEAN,PDEV,PMAX,PMIN,N,NLOOP,RT6N,RT7N
      INTEGER ANS
      NAMELIST/AWLS/NL,XPER,ANS
      DATA NL,XPER,ANS/100,0.,1/
      NLOOP=NL
      CALL RANSET(.05)
      READ AWLS
      PRINT AWLS
      DO 60 I=1,8
      SRT(I)=0.
   60 SUMDIF(I)=0.
      SRTAA=0.
      SRTT=0.
      RTASD=0.
      RTTSD=0.
      ADI=103.778
      EQUIP(1)=ADI
      CONTF=631.305
      EQUIP(2)=CONTF
      AISERV=2732.240
      EQUIP(3)=AISERV
      ELSERV=7936.508
      EQUIP(4)=ELSERV
      RUSERV=425.894
```

```
AICOMP=380.620
EQUIP(6)=AICOMP
ATC=716.332
EQUIP(7)=ATC
CADC=41.571
EQUIP(8)=CADC
ELCOMP=274.650
EQUIP(9)=ELCOMP
GSREC=499.251
EQUIP(10)=GSREC
HSI=343.643
EQUIP(11)=HSI
INS=1033.058
EQUIP(12)=INS
MCC=626.566
EQUIP(13)=MCC
NAVREC=1474.926
EQUIP(14)=NAVREC
NAVSEL=730.994
EQUIP(15)=NAVSEL
PAGYRO=381.534
EQUIP(16)=PAGYRO
PRGYRO=1538.462
EQUIP(17)=PRGYRO
RADIND=493.097
EQUIP(18)=RADIND
RADRT=234.632
EQUIP(19)=RADRT
RRGYRO=1538.462
EQUIP(20)=RRGYRO
RGACOM=341.647
EQUIP(21)=RGACOM
RDR=183.9
EQUIP(22)=RDR
STACC=197.668
EQUIP(23)=STACC
TPLC=407.830
EQUIP(24)=TPLC
VGYRO=381.534
EQUIP(25)=VGYRO
YDCOMP=304.044
EQUIP(26)=YDCOMP
EQUIP(27)=1072.961
EQUIP(28)=552.792
EQUIP(29)=259.538
EQUIP(30)=2066.116
EQUIP(31)=1472.754
EQUIP(32)=906.618
EQUIP(33)=10000.
EQUIP(34)=10000.
EQUIP(35)=10000000.
EQUIP(36)=142857.143
EQUIP(37)=10000000.
EQUIP(38)=200000.
EQUIP(39)=500000.
EQUIP(40)=200000.
EQUIP(41)=1000000.
EQUIP(42)=10000000.
EQUIP(43)=1000000.
EQUIP(44)=10000000.
EQUIP(45)=166666.667
EQUIP(46)=11671.335
EQUIP(47)=49504.951
EQUIP(48)=46685.341
```

```
      RT(8,N)=DEXP(-1.*SUM28*TIME(8))
      XMTBF(8)=1./SUM28
      EL1A=(4./MTBF(37))+(4./MTBF(35))+(5./MTBF(41))+(5./MTBF(34)

     6(1./MTBF(40))+(2./MTBF(49))+(2./MTBF(47))
      EL1B=(2./MTBF(45))+(6./MTBF(38))+(2./MTBF(46))+(2./MTBF(48)

     7(1./MTBF(44))+(4./MTBF(43))+(1./MTBF(39))
      EL1=EL1A+EL1B
      EL2=(1./MTBF(41))+(1./MTBF(34))
      EL3=1./MTBF(49)
      EL4=1./MTBF(48)
      EL5=(1./MTBF(47))+(1./MTBF(45))
      EL6=(1./MTBF(41))+(1./MTBF(34))
      EL7=1./MTBF(46)
      EG1=(1./MTBF(51))+(8./MTBF(41))+(1./MTBF(42))+(1./MTBF(35))

     8(8./MTBF(50))+(4./MTBF(38))+(1./MTBF(43))+(1./MTBF(44))
      EG2=(1./MTBF(41))+(1./MTBF(50))
      DO 32 K=1,8
      EXPL1=(DEXP(-1.*TIME(K)*EL1))*((3.-(2.*(DEXP(-1.*TIME(K)*EL
)
     9**2.)*(3.-(2.*(DEXP(-1.*TIME(K)*EL3))))*(3.-(2.*(DEXP(-1.*
     1TIME(K)*EL4))))
      EXPL2=(3.-(2.*(DEXP(-1.*TIME(K)*EL5))))*(2.-DEXP(-1.*TIME(K

     2EL6))*(3.-(2.*(DEXP(-1.*TIME(K)*EL7))))
      RLOC(K)=EXPL1*EXPL2
      RGS(K)=DEXP(-1.*TIME(K)*EG1)*((3.-(2.*(DEXP(-1.*TIME(K)*EG2
**4
     1.)
      RGRND(K)=RLOC(K)*RGS(K)
   32 RT(K,N)=RT(K,N)*RGRND(K)
      RTAA(N)=RT(4,N)*RT(5,N)*RT(6,N)*RT(7,N)*RT(8,N)
      RTT(N)=RT(1,N)*RT(2,N)*RT(3,N)*RTAA(N)
      IF(ANS.EQ.0)GOTO 210
      CALL SAFETY
  210 DO 70 I=1,8
   70 SRT(I)=RT(I,N)+SRT(I)
      SRTAA=RTAA(N)+SRTAA
      SRTT=RTT(N)+SRTT
      IF(N.EQ.1)GOTO 100
      DO 80 I=1,8
   80 NUMAX(I)=DMAX1(RT(I,N),NUMAX(I))
      MAXRTA=DMAX1(RTAA(N),MAXRTA)
      MAXRTT=DMAX1(RTT(N),MAXRTT)
      GOTO 110
  100 DO 90 I=1,8
   90 NUMAX(I)=RT(I,N)
      MAXRTA=RTAA(N)
      MAXRTT=RTT(N)
      IF(N.EQ.1)GOTO 120
  110 DO 130 I=1,8
  130 NUMIN(I)=DMIN1(RT(I,N),NUMIN(I))
      MINRTA=DMIN1(RTAA(N),MINRTA)
      MINRTT=DMIN1(RTT(N),MINRTT)
      GOTO 40
  120 DO 140 I=1,8
  140 NUMIN(I)=RT(I,N)
      MINRTA=RTAA(N)
      MINRTT=RTT(N)
   40 CONTINUE
      DO 150 I=1,8
  150 MEAN(I)=SRT(I)/FLOAT(NLOOP)
```

```
      RTTMN=SRTT/FLOAT(NLOOP)
      DO 160 N=1,NLOOP
      DO 170 I=1,8
      DIFRTM(I)=RT(I,N)-MEAN(I)
      IF(DIFRTM(I).LT.0.0000000000000000000001)GOTO 175
      DIF(I)=(RT(I,N)-MEAN(I))**2.
      GOTO 170
  175 DIF(I)=0.
  170 SUMDIF(I)=DIF(I)+SUMDIF(I)
      RTADIF=(RTAA(N)-RTAAMN)**2.
      RTTDIF=(RTT(N)-RTTMN)**2.
      RTASD=RTADIF+RTASD
      RTTSD=RTTDIF+RTTSD
  160 CONTINUE
      DO 180 I=1,8
  180 DEV(I)=DSQRT(SUMDIF(I)/(FLOAT(NLOOP)-1.))
      DEVRTA=DSQRT(RTASD/(FLOAT(NLOOP)-1.))
      DEVRTT=DSQRT(RTTSD/(FLOAT(NLOOP)-1.))
      PRINT*, " "
      PRINT*, " "
      PRINT*, " "
      PRINT*,"                              RELIABILITY ANALYSIS"
      PRINT*," "
      DO 190 I=1,8
      PRINT*," "
      PRINT*," "
      PRINT*," "
      PRINT*," "
      IF(I.EQ.1)PRINT*,"           LOC CAPTURE TO ARM G/S"
      IF(I.EQ.2)PRINT*,"           ARM G/S TO G/S CAPTURE"
      IF(I.EQ.3)PRINT*,"           G/S CAPTURE TO APPROACH ARM"
      IF(I.EQ.4)PRINT*,"           APPROACH ARM TO LAND ARM (100 F
"
      IF(I.EQ.5)PRINT*,"      LAND ARM (100 FT) TO FLARE ENGAGE (
T)"
      IF(I.EQ.6)PRINT*,"         FLARE ENGAGE (45 FT) TO DECRAB (2
)"
      IF(I.EQ.7)PRINT*,"           DECRAB (20 FT) TO TOUCHDOWN"
      IF(I.EQ.8)PRINT*,"           TOUCHDOWN TO STOP"
      PRINT*, " "
      PRINT*,"     MEAN TIME =                  ", XMEAN(I)
      PRINT*,"     STD.DEV. OF TIME =           ", STDDEV(I)
      PRINT*,"     MTBF =                       ", XMTBF(I)
      PRINT*,"     VARIATION =                  ", XPER
      PRINT*,"     MEAN OF RELIABILITY =        ", MEAN(I)
      PRINT*,"     STD.DEV. OF RELIABILITY =    ", DEV(I)
      PRINT*,"     MAX VALUE =                  ", NUMAX(I)
  190 PRINT*,"     MIN VALUE =                  ", NUMIN(I)
      PRINT*, " "
      PRINT*, " "
      PRINT*, " "
      PRINT*, " "
      PRINT*, "                 TOTAL RELIABILITY FROM APPROACH ARM T
OP"
      PRINT*, " "
      PRINT*,"     MEAN OF RELIABILITY =        ", RTAAMN
      PRINT*,"     STD.DEV. OF RELIABILITY =    ", DEVRTA
      PRINT*,"     MAX VALUE =                  ", MAXRTA
      PRINT*,"     MIN VALUE =                  ", MINRTA
      PRINT*, " "
      PRINT*, " "
      PRINT*, " "
      PRINT*, " "
```

```
      PRINT*,"      MEAN OF RELIABILITY =      ", RTTMN
      PRINT*,"      STD. DEV.  OF RELIABILITY = ", DEVRTT
      PRINT*,"      MAX VALUE =                 ", MAXRTT
      PRINT*,"      MIN VALUE =                 ", MINRTT
      IF(ANS.EQ.0)GOTO220
      PRINT*," "
      PRINT*," "
      PRINT*," "
      PRINT*," "
      PRINT*,"                          SAFETY ANALYSIS"
      DO 195 I=1,11
      PRINT*," "
      PRINT*," "
      PRINT*," "
      IF(I.EQ.1)PRINT*,"        SYSTEM OPERATIONAL"
      IF(I.EQ.2)PRINT*,"       NON-CRITICAL FAILURE AND SUCCESSFU
A"
      IF(I.EQ.3)PRINT*,"   CRITICAL FAILURE TO SINGLE CHANNEL AND
ES
     1SFUL R/GA"
      IF(I.EQ.4)PRINT*,"     WHEEL SPIN-UP NOT DETECTED AND SUCCE
. R
     1/GA"
      IF(I.EQ.5)PRINT*,"      NON-CRITICAL FAILURE DURING ROLLOUT
      IF(I.EQ.6)PRINT*,"           BACK-UP ROLLOUT MODE"
      IF(I.EQ.7)PRINT*,"     CRITICAL FAILURE TO SINGLE CHANNEL D
 R
     1OLLOUT"
      IF(I.EQ.8)PRINT*,"    LOCALIZER FAILURE AND SUCCESSFUL R/GA
      IF(I.EQ.9)PRINT*,"             SAFETY HAZARD"
      IF(I.EQ.10)PRINT*,"   ATTENUATED SAFETY HAZARD (NO PILOT VI
.IT
     1Y)"
      IF(I.EQ.11)PRINT*,"   ATTTENUATED SAFETY HAZARD (LIMITED PI
/IS
     1IBILITY)"
      PRINT*," "
      PRINT*,"      PROBABILITY = ", PMEAN(I)
      PRINT*,"      STD. DEV.  =  ", PDEV(I)
      PRINT*,"      MAX VALUE =   ", PMAX(I)
      PRINT*,"      MIN VALUE =   ", PMIN(I)
  195 CONTINUE
  220 STOP
      END
      SUBROUTINE SAFETY
      DOUBLE PRECISION P40,RT6N,RT7N,PFAIL1,PFAIL2,PFAIL3
      DOUBLE PRECISION DEL(11),EL1A,EL1B,MTBF(52),EL1,EL2,EL3,EL4

      DOUBLE PRECISION EL6,EL7,TIME(9),SUM26,SUM27,SUM28,RT(8,100

      DOUBLE PRECISION PMEAN(11),PDEV(11),PMAX(11),PMIN(11),RRGA(

      DOUBLE PRECISION PED(3),PATH(46,100),G(3),EXPL1,EXPL2,LOCR(

      DOUBLE PRECISION P(11,100),AT(10),P1(10),PP1(10),DPP(10),AT

      DOUBLE PRECISION P2(3),PP2(3),SUMP(11),SUMDIF(11),DIFF(11),

      DOUBLE PRECISION PEDP,DTTP,DTT1,DTT2,DTT3,TDWSP,TD1,TD2,TD3

      DOUBLE PRECISION TD5,PINS25,PINS1,PINS2,P27,PSH,DT,P28A1,DP
```

```
      DOUBLE PRECISION F41A(3),FF41A(3),DPF412,DPF413,F41A2,F45A2
      COMMON MTBF,EL1,EL2,EL3,EL4,EL5,EL6,EL7,TIME,SUM26,SUM27,SU

      COMMON PMEAN,PDEV,PMAX,PMIN,N,NLOOP,RT6N,RT7N
      RGA=DEXP(-1.*(1./MTBF(27))*TIME(9))
      RRGA(1)=1.-(2.*RGA)+(RGA**2.)
      RRGA(2)=(2.*RGA)-(2.*RGA*RGA)
      RRGA(3)=RGA**2.
      RRGA(4)=1.-RGA
      RRGA(5)=RGA
      FEDP=DEXP(-1.*(1./MTBF(27))*TIME(6))
      FED(1)=1.-DEXP(-1.*(SUM26-(2.*(1./MTBF(27))))*TIME(6))
      FED(2)=2.*FEDP-(2.*(FEDP**2.))
      FED(3)=1.-(2.*FEDP)+(FEDP**2.)
      G(1)=TIME(6)
      G(2)=TIME(7)+(1./3600.)
      G(3)=TIME(8)-(1./3600.)
      DO 901 I=1,3
      EXPL1=(DEXP(-1.*G(I)*EL1))*((3.-(2.*(DEXP(-1.*G(I)*EL2))))*
*
     1(3.-(2.*(DEXP(-1.*G(I)*EL3))))*(3.-(2.*(DEXP(-1.*G(I)*EL4))

      EXPL2=(3.-(2.*(DEXP(-1.*G(I)*EL5))))*(2.-DEXP(-1.*G(I)*EL6)

     12.*(DEXP(-1.*G(I)*EL7))))
  901 LOCR(I)=EXPL1*EXPL2
      PATH(1,N)=FED(1)*RRGA(1)
      PATH(2,N)=FED(1)*RRGA(2)
      PATH(3,N)=FED(1)*RRGA(3)
      PATH(4,N)=FED(2)*RRGA(4)
      PATH(5,N)=FED(2)*RRGA(5)
      PATH(6,N)=FED(3)
      PATH(7,N)=RT6N
      PFAIL1=1.-LOCR(1)
      PATH(30,N)=PATH(1,N)*PFAIL1
      PATH(31,N)=PATH(2,N)*PFAIL1
      PATH(32,N)=PATH(3,N)*PFAIL1
      PATH(33,N)=PATH(4,N)*PFAIL1
      PATH(34,N)=PATH(5,N)*PFAIL1
      PATH(35,N)=PATH(6,N)*PFAIL1
      PATH(36,N)=PFAIL1*RT6N*RRGA(1)
      PATH(37,N)=PFAIL1*RT6N*RRGA(2)
      PATH(38,N)=PFAIL1*RRGA(3)*RT6N
      DTTP=DEXP(-1.*(1./MTBF(27))*TIME(7))
      DTT1=1.-DEXP(-1.*(SUM27-(2.*(1./MTBF(27))))*TIME(7))
      DTT2=2.*DTTP-(2.*(DTTP**2.))
      DTT3=1.-(2.*DTTP)+(DTTP**2.)
      PATH(8,N)=DTT1*RRGA(1)
      PATH(9,N)=DTT1*RRGA(2)
      PATH(10,N)=DTT1*RRGA(3)
      PATH(11,N)=DTT2*RRGA(4)
      PATH(12,N)=DTT2*RRGA(5)
      PATH(13,N)=DTT3
      PATH(14,N)=RT7N
      TDWSP=DEXP(-1.*(1./MTBF(27))*(1./3600.))
      TD1=1.-DEXP(-1.*(SUM28-(2./MTBF(27))-(1./MTBF(28)))*(1./360

      TD2=(2.*TDWSP)-(2.*(TDWSP**2.))
      TD3=1.-(2.*TDWSP)+(TDWSP**2.)
      TD4=1.-DEXP(-1.*(1./MTBF(28))*(1./3600.))
      TD5=DEXP(-1.*SUM28*(1./3600.))
      PATH(15,N)=TD1*RRGA(1)
      PATH(16,N)=TD1*RRGA(2)
```

```
      PATH(20,N)=TD3
      PATH(21,N)=TD4*RRGA(1)
      PATH(22,N)=TD4*RRGA(2)
      PATH(23,N)=TD4*RRGA(3)
      PATH(24,N)=TD5
      PINS25=DEXP(-1.*(1./MTBF(30))*(TIME(8)-(1./3600.)))
      PINS1=(2.*PINS25)-(2.*(PINS25**2.))
      PINS2=1.-(2.*PINS25)+(PINS25**2.)
      PATH(25,N)=1.-DEXP(-1.*(SUM28-(1./MTBF(29)))*(TIME(8)-(1./3
))
     1+PINS1+PINS2
      PATH(26,N)=1.-DEXP(-1.*(1./MTBF(31))*(TIME(8)-(1./3600.)))
      P27=DEXP(-1.*(1./MTBF(32))*(TIME(8)-(1./3600.)))
      PATH(27,N)=(2.*P27)-(2.*(P27**2.))
      PATH(28,N)=1.-(2.*P27)+(P27**2.)
      PATH(29,N)=DEXP(-1.*SUM28*(TIME(8)-(1./3600.)))
      DO 902 I=1,7
  902 PATH(I,N)=PATH(I,N)*LOCR(1)
      PFAIL2=1.-LOCR(2)
      PATH(39,N)=PFAIL2*(1.-DEXP(-1.*(SUM28+(1./MTBF(14))-(1./MTB
))
     1*(TIME(8)-(1./3600.))))
      P40=DEXP(-1.*(1./MTBF(52))*(TIME(8)-(1./3600.)))
      PATH(40,N)=PFAIL2*((2.*P40)-(2.*(P40**2.)))
      PATH(41,N)=PFAIL2*(1.-(2.*P40)+(P40**2.))
      PATH(42,N)=PFAIL2*DEXP(-1.*SUM28*(TIME(8)-(1./3600.)))
      PFAIL3=1.-LOCR(3)
      PATH(43,N)=LOCR(2)*PFAIL3*(1.-DEXP(-1.*(SUM28+(1./MTBF(14))
'MT
     1BF(29)))*(TIME(8)-(1./3600.))))
      PATH(44,N)=LOCR(2)*PFAIL3*((2.*P40)-(2.*(P40**2.)))
      PATH(45,N)=LOCR(2)*PFAIL3*(1.-(2.*P40)+(P40**2.))
      PATH(46,N)=LOCR(2)*PFAIL3*DEXP(-1.*SUM28*(TIME(8)-(1./3600.

      DO 700 I=8,14
  700 PATH(I,N)=PATH(I,N)*PATH(7,N)
      DO 710 I=15,24
  710 PATH(I,N)=PATH(I,N)*PATH(14,N)
      DO 720 I=25,29
  720 PATH(I,N)=PATH(I,N)*PATH(24,N)*LOCR(2)*LOCR(3)
      DO 888 I=39,46
  888 PATH(I,N)=PATH(I,N)*PATH(24,N)
C     P(I,N):  I IS THE INDEX FOR 11 DIFFERENT PROBABILITIES TO B

C     COMPUTED
      P(1,N)=PATH(29,N)
      P(2,N)=PATH(2,N)+PATH(3,N)+PATH(9,N)+PATH(10,N)+PATH(16,N)+
17
     1,N)
      P(3,N)=PATH(5,N)+PATH(12,N)+PATH(19,N)
      P(4,N)=PATH(22,N)+PATH(23,N)
      P(5,N)=PATH(25,N)
      P(6,N)=PATH(26,N)+PATH(39,N)+PATH(42,N)+PATH(43,N)+PATH(46,
TH
     1(40,N)+PATH(44,N)
      P(7,N)=PATH(27,N)
      PSH=PATH(1,N)+PATH(4,N)+PATH(6,N)+PATH(8,N)+PATH(11,N)+PATH
)+
     1PATH(15,N)+PATH(18,N)+PATH(20,N)+PATH(21,N)+PATH(30,N)+PATH

     1PATH(35,N)+PATH(36,N)
      P(9,N)=PSH+PATH(28,N)+PATH(41,N)+PATH(45,N)
      P(8,N)=PATH(31,N)+PATH(32,N)+PATH(34,N)+PATH(37,N)+PATH(38,
```

```
      AT(1)=5.
      AT(2)=6.9
      AT(3)=8.6
      AT(4)=10.2
      AT(5)=12.
      AT(6)=13.4
      AT(7)=14.9
      AT(8)=18.
      AT(9)=19.5
      AT(10)=21.
      DO 600 I=1,10
      P1(I)=DEXP(-1.*(1./MTBF(32))*((AT(I)/3600.)+DT))
      P41(I)=DEXP(-1.*(1./MTBF(52))*((AT(I)/3600.)+DT))
      PF41(I)=1.-(2.*P41(I))+(P41(I)**2.)
  600 PF1(I)=1.-(2.*P1(I))+(P1(I)**2.)
      DO 610 I=2,10
      DPF41(I)=PF41(I)-PF41(I-1)
  610 DPF(I)=PF1(I)-PF1(I-1)
      P28A1=PF1(1)+(DPF(2)*.9)+(DPF(3)*.8)+(DPF(4)*.7)+(DPF(5)*.6

     16)*.4)+(DPF(7)*.2)+(DPF(8)*.1)+(DPF(9)*.05)
      P41A1=PF41(1)+(DPF41(2)*.9)+(DPF41(3)*.8)+(DPF41(4)*.7)+(DP

     1.6)+(DPF41(6)*.4)+(DPF41(7)*.2)+(DPF41(8)*.1)+(DPF41(9)*.05

      P45A1=P41A1
      P(10,N)=PSH+(P28A1*PATH(24,N)*LOCR(2)*LOCR(3))+(P41A1*PATH(

     1PFAIL2)+(P45A1*PATH(24,N)*LOCR(2)*PFAIL3)
C       ATTENUATION FUNCTION WITH LIMITED PILOT VISIBILITY
      AT2(1)=3.
      AT2(2)=5.
      AT2(3)=6.9
      DO 620 I=1,3
      P41A(I)=DEXP(-1.*(1./MTBF(52))*((AT2(I)/3600.)+DT))
      P2(I)=DEXP(-1.*(1./MTBF(32))*((AT2(I)/3600.)+DT))
      PF41A(I)=1.-(2.*P41A(I))+(P41A(I)**2.)
  620 PF2(I)=1.-(2.*P2(I))+(P2(I)**2.)
      DPF412=PF41A(2)-PF41A(1)
      DPF2=PF2(2)-PF2(1)
      DPF413=PF41A(3)-PF41A(2)
      DPF3=PF2(3)-PF2(2)
      P28A2=PF2(1)+(DPF2*.6)+(DPF3*.1)
      P41A2=PF41A(1)+(DPF412*.6)+(DPF413*.1)
      P45A2=P41A2
      P(11,N)=PSH+(P28A2*PATH(24,N)*LOCR(2)*LOCR(3))+(P41A2*PATH(

     1PFAIL2)+(P45A2*PATH(24,N)*LOCR(2)*PFAIL3)
      IF(N.GE.2)GOTO7
      DO 630 I=1,11
      SUMP(I)=0.
  630 SUMDIP(I)=0.
    7 DO 640 I=1,11
  640 SUMP(I)=P(I,N)+SUMP(I)
      IF(N.EQ.1)GOTO 802
      DO 801 I=1,11
      PMAX(I)=DMAX1(P(I,N),PMAX(I))
  801 PMIN(I)=DMIN1(P(I,N),PMIN(I))
      GOTO 804
  802 DO 803 I=1,11
      PMAX(I)=P(I,N)
  803 PMIN(I)=P(I,N)
  804 IF(N.NE.NLOOP)GOTO 750
      DO 650 I=1,11
```

```
      DO 650 I=1,11
  650 PMEAN(I)=SUMP(I)/FLOAT(NLOOP)
      DO 660 J=1,NLOOP
      DO 670 I=1,11
      DEL(I)=P(I,J)-PMEAN(I)
      IF(DEL(I).LT.0.000000000000000000001)GOTO 800
      DIFF(I)=(P(I,J)-PMEAN(I))**2.
      GOTO 670
  800 DIFF(I)=0.
  670 SUMDIP(I)=DIFF(I)+SUMDIP(I)
  660 CONTINUE
      DO 680 I=1,11
  680 PDEV(I)=DSQRT(SUMDIP(I)/(FLOAT(NLOOP)-1.))
  750 RETURN
      END
```

APPENDIX C

EXTRACTS, C-141 AWLS OPERATIONAL FLIGHT TESTS

AFFDL-TR-77-39

This report presents the results of approximately 1200 approaches and landings of which 82 were accomplished in actual Category III weather conditions (RVR less than 1200 feet) including 14 landings in a reported RVR of zero. The tests were conducted with a C-141 aircraft flying only Category II or III ground ILS equipment on runways furnished with U.S. Standard ALSF-1 approach lighting and touchdown Zone Lighting (TDZL systems.) Since the step 4 approach light setting was considered optimum, it serves as the basis for evaluation for this test.

The conclusions of the test program were subjective in nature and based upon the experience of the project test pilot: however, a majority reflect the consensus of opinion of other participating pilots and test observers. Conclusions were as follows:

1. Basically four parameters comprise the landing/go-around decision criteria:
    - a. Aircraft position relative to glideslope and localizer.
    - b. Aircraft lateral and vertical rates
    - c. System integrity.
    - d. Aircraft attitude.
2. An automatic landing should be the primary mode for Category III landings.
3. A specific point of landing committal should be determined based upon aircraft performance characteristics.
4. Step 4 approach light setting is optimum.
5. Aircraft landing lights provide no assistance for the landing and produce undesirable reflections at altitude.
6. The strobe and approach lights are useful down to RVR's of approximately 300 feet.
7. Roll bars in the ALSF-1 lighting system were generally ineffective aids.

8. The runway threshold lights were very ineffective.

9. The touchdown zone lights were generally very effective and provided the primary cues for operation in RVR's less than 800 feet. The touchdown Zone (TDZ) lights were positively acquired at approximately 50 AGL (Absolute Ground Level) for an RVR estimated to be 200 feet.

10. Although visual verification of lateral position and rate were possible before touchdown (point of commitment for the test vehicle), The TDZ lights did not provide cues to complete a flare. Overall attitude and altitude information were lacking.

11. Based upon the test aircraft geometry, the lowest RVR which provides a se -to-land capability is 1000 feet reported RVR and then only if all flight conditions are optimum.

12, The runway edge lights were generally not a factor in the final visual field upon landing.

13. If lateral excursions from the runway centerline are kept within $\pm$ 30 feet, the centerline lights provide acceptable cues to complete visual takeoffs and landings for RVR as low as 200 feet estimated (based upon pilot eye height of approximately 15 feet above ground).

14. Major inadequacy of the runway lighting system is the lack of longitudinal information and corresponding taxiway turnoff definition for ground operation.

15. The onset of taxi/ground operation difficulties correlates to a reported RVR of approximately 600 feet.

16. Unacceptable localizer signal oscillations caused by overflight of the transmitter antenna by other aircraft.

17. Compared to normal instrument flight, the task involved with completely instrument landings demand considerably increased pilot precision and concentration and consequently greater overall workload.

18. Due to capability limitations in general cockpit management and restricted instrument crosscheck capability, manual approaches are not feasible as a primary operational mode.

19. The unique wing low decrab instrument maneuver was initially difficult to become accustomed to on instruments. Although some flexibility and touchdown point accuracy were gained, the tests provided no definite support for the re-

quirement of the wing low decrab technique as long as 10 KTS direct crosswind was not exceeded.

20. Biomedical tests were inconclusive and yielded little difference in results compared to data taken during normal Category II approaches.

21. If the criteria for a satisfactory backup mode consists of providing only control task capability, the manual mode of operation qualifies throughout all phases of approach and landing. The manual mode is satisfactory as a primary technique for landing rollout and takeoff.

RECOMMENDATIONS

As a result of experience in this program, the project pilot offered a number of recommendations:

1. Runway threshold definition is critical and a major effort for improved effectiveness should be undertaken.

2. All Category III landings should be totally instrument landings at least to touchdown point.

3. Rows of lights perpendicular to the runway centerline, extending approximately 15 feet to either side, could be located directly abeam each useable taxiway turnoff. In addition to positive turnoff definition, these lights would provide longitudinal information.

4. The RVR breakdown for Category III should be aligned to the correlation between actual RVR and reported RVR. Based upon these test results, this correlation suggests a breakdown as follows:

Category IIIa - RVR 1200 ft to 600 feet
Autoland, visual rollout, visual taxi.

Category IIIb - RVR less than 600 feet

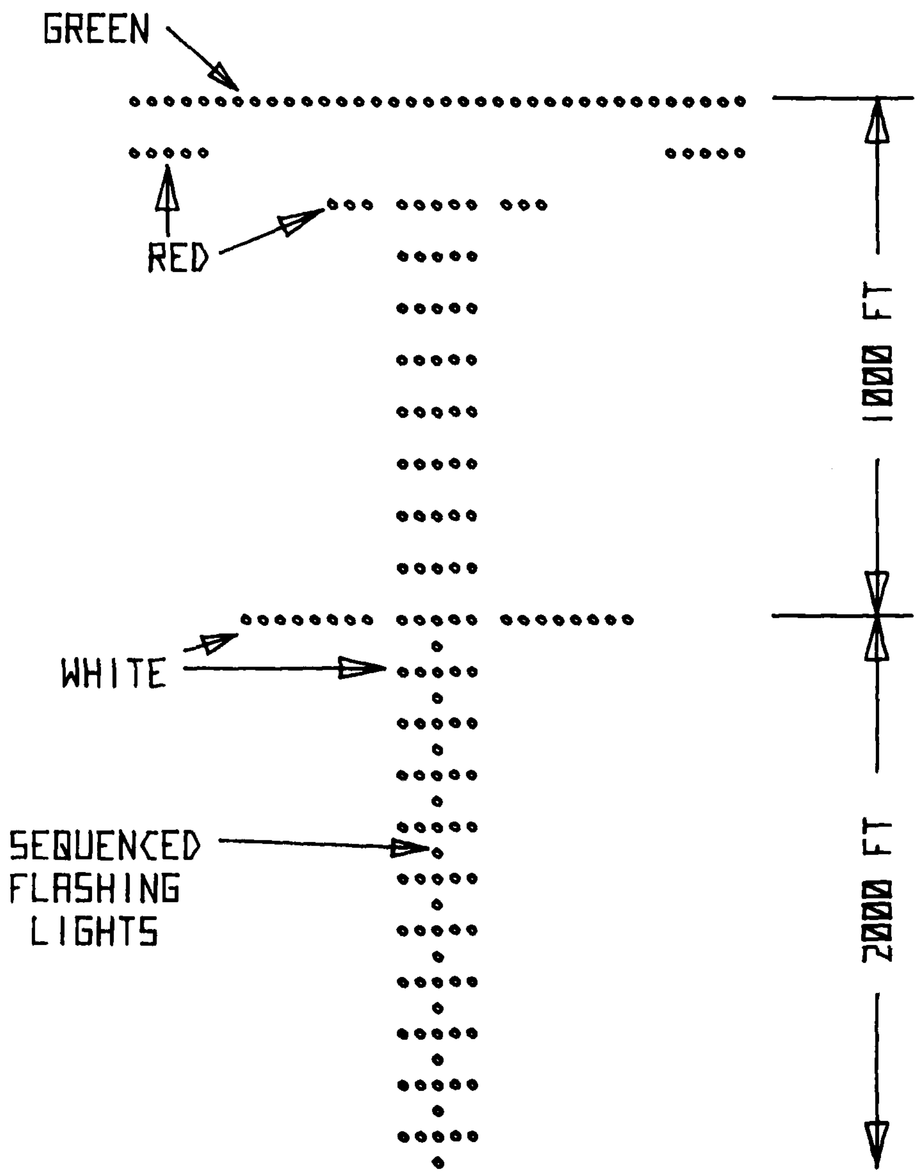
Category IIIb - RVR less than 600 feet
Autoland, auto-rollout, * auto-taxi**

* The assessment of conditions down to 200 feet estimated RVR indicates that visual rollout/takeoff could be conducted. Auto is specified to ensure capability based upon excellent instrument rollout results and also to include capability to actual zero visibility.

** As suggested earlier, visual assistance, such as taxiway centerline lights may provide improvement sufficient to visually taxi in RVR conditions less than 600 feet reported.

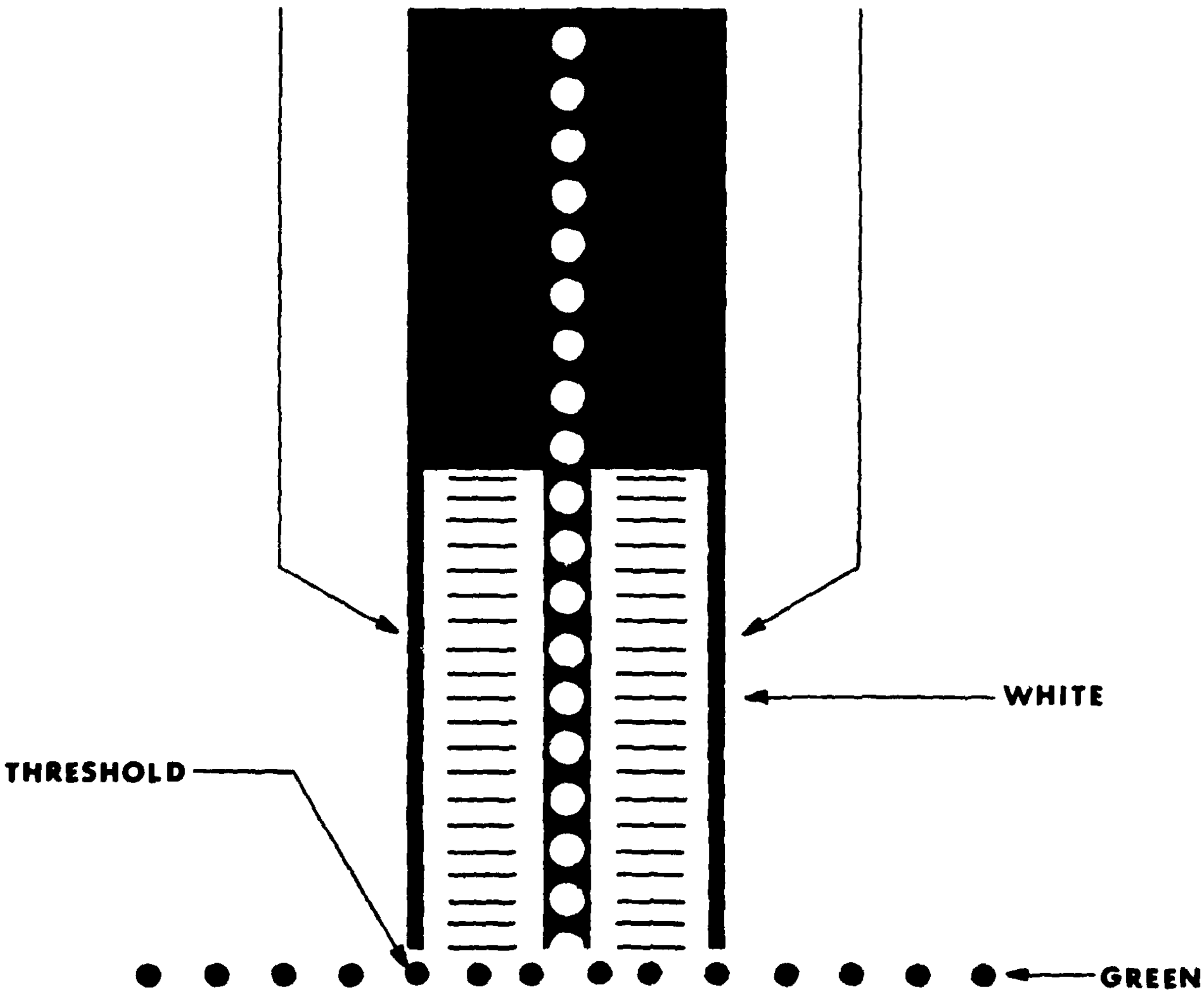
5. Improvements in instrument displays integrating failure warning and performance parameters with the control display could achieve feasibility for the manual mode to be a primary mode.

6. Considering the narrow bounds of pilot capability during manual approaches, the display integration process should focus upon representation of all the integrated parameters through flight director presentation.



(HIGH INTENSITY)
STANDARD LENGTH 3000 FEET

TOUCHDOWN ZONE LIGHTING
(TDZL)



*U.S.Government Printing Office: 1980 — 657-084/440